U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-277 089

Mine Drainage Control from Metal Mines in a Subalpine Environment
A Feasibility Study

Montana Dept of Natural Resources and Conservation, Helena

Prepared for

Industrial Environmental Research Lab, Cincinnati, Ohio

Nov 77

PB 277 089

EPA-600/2-77-224
NOVEMBER 1977

Environmental Protection Technology Series

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-224	2.	3. RECIPIENT'S ACCESSION NO. PB277089
4. TITLE AND SUBTITLE Mine Drainage Control from Metal Mines in a Subalpine Environment - A Feasibility Study		5. REPORT DATE November 1977 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Montana Department of Natural Resources and Conservation 32 South Ewing Helena, Montana 59601		10. PROGRAM ELEMENT NO. 1BB604
		11. CONTRACT/GRANT NO. Grant S 802671
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Laboratory - Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final/June 1973 - August '77
		14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Investigations of the McLaren mine and mill areas and the Glengary mine area in the vicinity of Cooke City, Montana, were undertaken from July 1973 through September 1975, to examine the acid mine drainage (AMD) from these sources and determine the feasibility of rehabilitating these subalpine mining areas and mill area. A biological study was conducted to determine the existing degraded biological conditions of streams affected by AMD and the extent of reclamation necessary to restore a viable fishery to the stream.

Reclamation proposed includes recontouring and revegetating land surfaces, sealing shafts in the mine area, and isolating the tailings from Soda Butte Creek.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS		c. COSATI Field/Group
Mining	Bioassay	Subalpine	Heavy metals	08/D
Tailings	Expenses	Montana	Fish tissue	08/G
Reclamation		Cooke City -		08/H
Water quality		Stillwater River		08/I
Geology		Clarke Fork		08/M
Hydrology		Soda Butte		08/B
		McLaren Mine		08/A
		Acid mine drainage		13/B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 181
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A09 - A01

EPA Form 2220-1 (9-73)

U.S. GOVERNMENT PRINTING OFFICE 1978— 797-140/[illegible]

EPA-600/2-77-224
November 1977

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A Feasibility Study

by

Montana Department of Natural Resources and Conservation
Engineering Bureau
Helena, Montana 59601

Grant No. S802671

Project Officer

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INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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CINCINNATI, OHIO 45268

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

In this report the technical and economic feasibility of reclaiming and preventing mine drainage from abandoned metal mines in a subalpine environment was determined. Alternative methods of controlling pollution from surface, and underground mines as well as tailings ponds were evaluated. This study has been one of the more comprehensive of its kind and the first for subalpine conditions.

Results of this work will be especially interesting to State and Federal agencies concerned with reclamation of abandoned metal mines and to mining firms faced with reclamation in subalpine environments. For further information contact the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Investigations of the McLaren mine and mill areas and the Glengary mine area in the vicinity of Cooke City, Montana, were undertaken from July 1973 through September 1975, to examine the acid mine drainage (AMD) from these sources and determine the feasibility of rehabilitating these subalpine mining areas and mill area. A biological study was conducted to determine the existing degraded biological conditions of streams affected by AMD and the extent of reclamation necessary to restore a viable fishery to the stream.

Reclamation proposed includes recontouring and revegetating land surfaces, sealing shafts in the mine areas, and isolating the tailings from Soda Butte Creek.

This report was submitted in fulfillment of Grant No. S802671 under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period June 18, 1973, to June 30, 1976, and work was completed as of August 1, 1977.

CONTENTS

Disclaimer ii
Foreword iii
Abstract iv
Illustrations vii
Tables ix
Acknowledgments x

1. Introduction 1
    Scope 1
    Objectives 1
    Project Description 2

2. Conclusions and Recommendations 3
    Introduction 3
    McLaren Mine Area 3
    Glengary Mine Area 4
    McLaren Mill Area 5

3. Legal Framework 7
    Authority 7
    Site and Mineral Right Acquisition 7

4. Environmental Inventory 8
    Cultural Environment 8
        Mining History
        Current Social and Economic Conditions
    Physical Environment 10
        Introduction
        Mine Areas
            Introduction
            Physical Resources and Conditions
            Geology
            Hydrology
            Water Chemistry
            The Mixing of Dissimilar Stream Waters
            Discussion
        Mill Area 48
            Introduction
            Geology
            Tailings Material
            Hydrology
            Water Chemistry
            Discussion

5. Biological Study 82
    Introduction 82
        Chemical Sampling
            Basic Chemical Parameters and Heavy Metal Analyses
            Field Physiochemical Determinations
            Stream Sediment Analyses
        Biological Studies
            Benthic Insects
            Fish Shocking
            Bioassays
            Fish Tissue Analyses
    Results 85
        Stillwater-McLaren Mine Area
            Chemical Sampling
            Biological Studies
        Clarks Fork-Glengary Mine Area
            Chemical Sampling
            Biological Studies
        Soda Butte-McLaren Mill Area
            Chemical Sampling
            Biological Studies
    Conclusions and Recommendations 101
        Stillwater-McLaren Mine Area
        Clarks Fork-Glengary Mine Area
        Soda Butte-McLaren Mill Area

6. Reclamation Alternatives 103
    McLaren Mine Area 103
    Glengary Mine Area. 107
    McLaren Mill Area 113
        Mill Tailings Removal
        Effluent Treatment
        Infiltration Control

References 123
Bibliography 125

Appendices 126
    A. Conversion Factors 126
    B. Climatic Data. 130
    C. Methods of Investigation 132
    D. Acid Mine Drainage Effects on Streams. 135
    E. Water Quality Analysis Data. 139
    F. Chemistry of Snow Samples. 154
    G. Summary of Well and Drilling Data. 155
    H. Water Levels-McLaren Mill Site 163

FIGURES

Number Page

1 Location of the study area 9
2 Location of Cooke City and the mine and mill areas 11
3 Sketch of the McLaren mine area 13
4 Sketch of the Glengary mine area 14
5 Relative percentage of water in the lower Glengary tunnel 16
6 Geologic map of sec. 11 and part of sec. 2, T. 9 S., R. 14 E., near Cooke City, Montana 17
7 Schematic cross section showing the thickness of unconsolidated deposits at the McLaren mine area 28
8 Hydrograph for Daisy Creek at site 109, McLaren mine area 30
9 Hydrograph for Fisher Creek at site 207, Glengary mine area 34
10 Iron versus sulfate plot for water samples collected at the lower adit (site 205), Glengary mine area 37
11 Flow versus specific conductance for waters collected at sites 109 and 207 39
12 Flow versus total suspended solids for Daisy and Fisher Creeks at their gauging stations 42
13 Metal loads at McLaren mine site for water year 1975 44
14 Water quality at McLaren mine site (July 30, 1975) 46
15 Metal loads at Glengary mine site for water year 1975 47
16 Sample site location map of the mill tailings area 50
17 Hydrographs for Soda Butte Creek at sites 317 and 322 for 1974 56
18 Hydrographs for Soda Butte Creek at sites 317 and 322 for 1975 57
19 Location of flow measurement sites at McLaren mill site (July 21, 1975) 58
20 Semilogarithmic plot of Soda Butte Creek hydrographs showing base flow for sites 317 and 322 60
21 Water table map of the McLaren mill site (May 21, 1974) 62
22 Water table map of the McLaren mill site (June 6, 1974) 63
23 Water table map of the McLaren mill site (July 12, 1974) 64
24 Water table map of the McLaren mill site (July 1, 1975) 65
25 Water table map of the McLaren mill site (September 9, 1975) 66
26 Flow versus sulfate plot for sites 317, 321, and 322 67
27 Isopleth map of field pH values from wells at the McLaren mill site (July 2, 1975) 71
28 Isopleth map of laboratory specific conductance from wells at the McLaren mill site (July 2, 1975) 72
29 Isopleth map of sulfate concentration from wells at the McLaren mill site (July 2, 1975) 74

30 Isopleth map of dissolved iron concentration from wells at the McLaren mill site (July 2, 1975). 75
31 McLaren tailings pond--diagrammatic vertical section 76
32 Generalized flow map showing direction of groundwater movement within the tailings (July 2, 1975) 78
33 Metal loads at McLaren mill site for water year 1975 81
34 Location of water quality and biological sampling stations 83
35 Variations in calcium plus magnesium at each station during the study period--Soda Butte Creek. 91
36 Variations in sulfate at each station during the study period--Soda Butte Creek 92
37 Variations in total alkalinity at each station during the study period--Soda Butte Creek. 93
38 Dissolved iron concentrations, Soda Butte Creek. 95
39 Dissolved iron concentrations at downstream stations 95
40 Length-mortality relationship in two bioassays in Soda Butte Creek 99
41 Proposed McLaren mine reclamation plan 104
42 Cross section of air seal. 109
43 Cross section of bulkhead seal 109
44 Proposed Glengary mine reclamation plan. 110
45 Cross section of McLaren mill pile and Soda Butte Creek before and after tailings removal 114
46 Proposed location of treatment plant and settling pond at McLaren mill area 117
47 Proposed lime neutralization process at McLaren mill area. 118
48 Cross section of proposed dam at McLaren mill tailings pile. . . . 120
49 Proposed location of new dam and proposed Soda Butte Creek channel at McLaren mill area 121

PHOTOS

1 Upper Glengary mine area showing disturbed area. 21
2 Upper Glengary mine area showing collapsed mine adit. 22
3 McLaren mine area showing disturbed area 24
4 McLaren mill area showing Soda Butte Creek 49
5 Soda Butte Creek near site 317 55

TABLES

Numbers Page

1 McLaren Mine Area Streamflow Data 25
2 McLaren Mine Observation Well--Depth to Water 27
3 Glengary Mine Observation Wells--Depth to Water 31
4 Fisher Creek Area Streamflow Data 33
5 Precipitation Data From Storage Precipitation Gauge, Fisher Creek Drainage Basin 35
6 Impact of a Storm on Runoff Quality At Site 103 45
7 Chemical Analyses of Drill Holes, McLaren Mill Site 52
8 McLaren Mill Site Streamflow Data 54
9 Flow Measurements Around McLaren Mill Tailings Pond, June 21, 1975 59
10 Heavy Metal Analyses of Stream Gravels, Stillwater Drainage. 87
11 Heavy Metal Concentrations in Fish Flesh from the Stillwater-McLaren Mine Stations, September 1975. 88
12 Heavy Metal Analyses of Stream Gravels, Clarks Fork Drainage. 89
13 Heavy Metal Concentrations in Fish Flesh from the Clarks Fork-Glengary Mine Stations, September 1975 90
14 Heavy Metal Analyses of Stream Gravels, Soda Butte Creek. . . 94
15 Total and Average Number of Benthic Insects Collected in Soda Butte Creek 96
16 Comparative Water Quality Data from Station 322 and 100% Soda Butte Creek Water 98
17 Heavy Metal Concentrations in Fish Flesh from the Soda Butte-McLaren Mill Sites 100
18 Characteristics of Mine Waste Materials at McLaren Mine Site 105
19 Cost of Reclamation at McLaren Mine Site. 107
20 Characteristics of Mine Waste Materials at Glengary Mine Site 111
21 Cost of Reclamation at Glengary Mine Site 112
22 Cost of Removing McLaren Mill Tailings. 115
23 Cost of Treating Effluent from McLaren Mill Tailings. 119
24 Cost of Controlling Infiltration into the McLaren Mill Dump 122

ACKNOWLEDGMENTS

The Department of Natural Resources and Conservation would like to thank Richard B. Berg, Grove L. Higgins Jr., Marvin R. Miller, John L. Sonderegger, Joseph J. Wallace Jr., and Laurence A. Wegelin of the Montana Bureau of Mines and Geology and Ken Knudson of the Montana Department of Fish and Game who provided most of the work and study involved in this project.

A special thanks is extended to Albert Brubaker, a local resident of Silver Gate, Montana, who provided many hours of untiring labor in collecting water samples, streamflow measurements, and performing other odd jobs for the project.

The Department also wishes to thank personnel from the Custer National Forest, Gallatin National Forest, and the U.S. Forest Service, Forestry Science Laboratory, Ogden, Utah for their cooperation and input to the study.

The following Department staff also contributed to this project: Richard L. Bondy, Project Manager; Michael R. Brown, Project Coordinator; Ann W. Crowner, Editor; and Melvin F. McBeath, Hydrographer.

SECTION 1

INTRODUCTION

Scope

The purpose of this project was to conduct a feasibility study of techniques for reduction and treatment of acid mine drainage (AMD) in an alpine/subalpine environment near Cooke City, Montana. A general discussion of the chemistry of AMD and its effects on streams is contained in Appendix D. The basic approach to the study included five study-work plans: a geohydrology study, water quality study, biological study, on-site evaluation of rehabilitation techniques, and visual resources study. The data collection included installation of groundwater level and stream gauging stations, and water quality sampling of both surface water and groundwater.

Objectives

The objectives of the feasibility study were:

1. To select the proper techniques to rehabilitate areas producing AMD in an alpine/subalpine environment and to demonstrate that AMD from hard rock mining can be controlled if proper preventive and corrective measures are taken. This is the major objective.

2. To assist mining companies or any other private concerns interested in the minerals of the area in determining the best methods of rehabilitation should they again mine the area.

3. To select the proper techniques to prevent further degradation of water quality in the Stillwater River, and Soda Butte and Fisher Creeks and to maintain the present fisheries in these streams.

4. To select the proper techniques to improve the water quality and to promote, where feasible, fisheries in the reaches of the Stillwater River, and Soda Butte and Fisher Creeks that are already contaminated and sterile.

5. To determine ways in which aesthetic values can be restored. The area, especially that contaminated reach of Soda Butte Creek near Cooke City, is viewed by many people as they enter or leave Yellowstone National Park.

6. To establish the feasibility of revegetating the old mine workings.

Project Description

The Montana Department of Natural Resources and Conservation (DNRC) directed the AMD feasibility study and contracted with the Montana Bureau of Mines and Geology to conduct a hydrogeological study of the project sites, including water quality studies. The Montana Department of Fish and Game was contracted to do a biological study of the streams affected by AMD.

Initial field work in 1973 included selection and sampling of several surface water quality monitoring stations at each of the three project sites. Ten observation wells were installed in the McLaren mill tailings pond area to study the groundwater regime of the tailings. Water levels were monitored, and each well was sampled periodically for water quality determinations.

Flow measurements, water level measurements, and water sampling continued throughout the winter and spring of 1973-74, as weather conditions permitted. Most of the project sites were accessible only by snowmobile; excessive snow depth and lost markers resulted in minimal data collection during part of the season.

A late spring delayed field work in 1974 until July. Additional observation wells were installed at the mill and mine sites in August. Three stream-gauging stations were installed in August, one in each of the three drainages involved below the AMD sources.

The 1975 field season included general geological review of the area and investigation of several suspected area of natural acid water formation. The hydrologic systems of the mine area were studied in more detail. An underground inspection of the Glengary mine was conducted, and a mobile auger, contracted from the Montana Highway Department, was used for deeper drilling in the mine areas. The auger also drilled 21 core and auger holes in the McLaren mill tailings. A seepage run on Soda Butte Creek was made adjacent to the tailings. Periodic sample collecting and streamflow and water level measuring continued through September 1975.

During the field season of 1975, a biological study was conducted to determine the existing degraded biological conditions of the streams within the project area, and to determine the extent of reclamation necessary to restore a viable fishery to the streams.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

Introduction

The factors influencing the extent of acid mine drainage in a subalpine environment appear to be: (1) mining methods employed, (2) topographic setting, (3) type and extent of mineralization, and (4) geologic setting and association.

We believe that rehabilitation at the McLaren mine, Glengary mine, and the McLaren mill sites is needed and feasible. The mine sites are above 2,743 m in a subalpine environment; the fragile nature of this type of ecosystem has been recognized, but the development of adequate rehabilitation procedures is still in the preliminary experimental stage. Experimental data from demonstration projects in this type of environment are definitely needed, as preliminary data gathered by the U.S. Forest Service show that introduced plant species are not capable of coping with the environment and providing the vegetative cover needed for slope stabilization. Projections of America's need for and potential supplies of mineral commodities (USGS, 1975; Haggard, 1975; Carson, 1975) suggest that this fragile environment will be further exploited for mining in the future. Conclusions and recommendations for rehabilitation at the three sites investigated are presented below.

McLaren Mine Area

During the 1975 water year (October 1, 1974 through September 30, 1975), the McLaren mine area contributed 154,800 kg acidity, 220,600 kg sulfate, and 14,500 kg of iron to Daisy Creek, a tributary of the Stillwater River. The mine area (6.9 ha) included 96,000 m^3 of disturbed mine material from an open pit gold mine and an adit to a small underground mine. No fish or benthic insects were found in Daisy Creek just below the mine. Even at a site 3 km from the mine no fish were found, and the total of benthic insects was severely reduced. Only two insects were found on four sampling dates. A bioassay conducted at this site resulted in all ten fish dying within 24 hours. Heavy metal analysis of the fish tissues from the bioassay revealed high concentrations of aluminum and copper, probably the cause of fish mortality.

The major problem at the McLaren mine site is the ponding of snowmelt and rainfall waters in the disturbed areas, resulting in runoff and groundwater emerging with high, heavy metal concentrations. A reclamation plan for reducing polluted runoff and groundwater flows is to bury the high sulfide materials in existing depressions and slope the disturbed area with suitable cover material. The cover material should be treated with lime to improve the plant-growing characteristics of the cover soil. The soil should then be fertilized, planted with native seed or cuttings from plants, and mulched to prevent erosion. Grading should be conducted in one year, and those areas not seeded the first year should be covered with mulch to prevent erosion. Any revegetation program should be coordinated with the U.S. Forest Service, Intermountain Forest and Range Experiment Station at Ogden, Utah.

The reclamation alternative also includes the construction of a lined drain trench from the seeps at the base of the highwall across the disturbed area, as well as a drain trench above the distrubed area to drain runoff away from the area. It has been estimated that this reclamation alternative would decrease the metal load that enters Daisy Creek by 79 percent. Cost of the reclamation at this site is estimated at $292,000.

Based upon the available information related to the mine area and the present data available concerning revegetation in a subalpine environment, it is recommended that a reclamation and revegetation program be initiated at the McLaren mine site as described in Section 6, Reclamation Alternatives. In conjunction with the reclamation activities, surface and groundwater should be monitored with respect to flow and quality, during and after construction.

Glengary Mine Area

The Glengary mine area contributed 28,000 kg acidity, 54,400 kg sulfate, 2,180 kg iron, and 1,720 kg aluminum to Fisher Creek during the 1975 water year. The major mine adit contributes almost half of these pollutants except for iron. The iron discharge was greater from the adit than that found in the creek, because the iron precipitated as the mine water flowed to the creek sampling point. At a site on Fisher Creek 4 km below the mine, a benthic insect survey showed 5.25 organisms per 0.08 m^2, as compared to 12 organisms at the control site. A 60-hour bioassay at this site revealed no mortalities. The heavy metal concentrations in the flesh of the bioassay fish were low at the Fisher Creek site.

Two sources of pollution in the Glengary mine area are the mine adit and the disturbed area near Lulu Pass. The major problem at the mine adit is the infiltration into the mine from two raises and from groundwater seeps through a fracture about 320 m from the portal. The problem at the disturbed area near Lulu Pass is the ponding of snowmelt and rainfall waters which eventually pass through the disturbed material. Some of the ponded water could also be a source of groundwater to the mine.

A reclamation plan for the Glengary mine area involves regrading and revegetating the disturbed area near Lulu Pass in a manner similar to the reclamation plan for the McLaren mine area. The two raises to the mine should be sealed, and the ground around the raises graded to slope away from the raises. The mine portals should be sealed with either a bulkhead or air seal. An air seal reduces oxidation of pyrites in the mine and is not a permanent seal if the mine is to be reopened. A bulkhead seal is not as easy to remove as an air seal, and the flooded mine waters pose an AMD problem if the bulkhead seal is removed. Reclamation should also include grading and revegetating the mine dump near the outlet of the Glengary mine.

Grading and revegetating the disturbed area near Lulu Pass should increase the runoff and decrease the production of acid load. It is estimated that the acid load from the disturbed area whould be reduced by 90 percent. Cost of grading and revegetation is estimated at $95,700. An air seal installed in the mine portals and grading should reduce the acid load originating in the Fisher Creek drainage by 79 percent. A bulkhead seal and grading should reduce discharge loads from the Fisher Creek drainage by 93 percent. Cost of the air seal is $18,000 and a bulkhead seal is $54,000.

It is recommended that the disturbed area near Lulu Pass be graded and revegetated, the two mine raises the sealed, and an air seal be installed in the mine portals of the Glengary mine. The mine dump near the Glengary mine should be graded and revegetated. A monitoring program to gather water quality and streamflow data should be conducted during and after construction.

McLaren Mill Area

During 1975, the McLaren mill area contributed 337,900 kg sulfate, and 113,900 kg iron to Soda Butte Creek. The mill tailings area is 260 and 150 m, and the tailings depth ranges from 0.03 to 9.7 m. The total number of benthic insects was severely reduced in Soda Butte Creek immediately below the tailings. Full recovery of benthic insects occurred 20 km downstream. Two 96-hour bioassays in Soda Butte Creek just below the tailings area resulted in 100 percent mortality on the first test and 80 percent on the second. Heavy metal analysis of the fish tissues revealed the iron concentration to be at least seven times higher in fish at this site as compared to fish from other sites. Iron appeared to be the cause of the mortality.

The major source of AMD at the McLaren mill area is the mill tailings pile. Water infiltrates the tailings material from Soda Butte Creek, from snowmelt and rainfall, and from runoff from the drainage above the tailings pile. Waters that enter the tailings, react with the sulfide tailings minerals, and pass through the tailings, return as mineralized springs, seeps, and groundwater, and degrade Soda Butte Creek below the tailings pond.

Three different alternatives were examined for reducing the AMD into Soda Butte Creek: (1) mill tailings removal, (2) effluent treatment, and (3) infiltration control. The first alternative would remove all mill tailings from their present location, revegetate the disturbed area, and rechannel Soda Butte Creek back to its original channel. Removal of the tailings would effectively remove the source of AMD, and the heavy metal loads entering Soda Butte Creek at the McLaren mill area would be reduced 100 percent. Disposal areas for the tailings material are old mine shafts, a new location free from surface or groundwater infiltration, or concentrating and smeltering at East Helena, Montana. The cost of removing the tailings and reshaping the area is estimated at $302,650; the cost of disposal at old mines is $68,700, new location $139,400, and smelting $3,045,000.

The second alternative of effluent treatment consists of building two dams and a typical lime treatment plant. This alternative should reduce iron loads to Soda Butte Creek by 80 percent at an initial cost of $483,100 and an annual maintenance cost of $29,300.

The last alternative for reducing heavy metal loads to Soda Butte Creek is infiltration control. An impervious dam would be installed across the lower (downstream) end of the tailings pile including the existing Soda Butte Creek channel. The existing Soda Butte channel next to the tailings pile should be filled, and a new sealed channel for the creek constructed immediately to the north of the existing channel. Thus, Soda Butte Creek would be channeled around the tailings pile and above the dam. Once the channel reaches the dam, a concrete drop structure would drop Soda Butte Creek back to its existing channel. A drainage ditch on the hillside above the tailings pile should be constructed to keep runoff from entering the tailings. This alternative should reduce iron loads to Soda Butte Creek by 95 percent at a cost of $156,610.

Recommendations for this site include the alternative for infiltration control. Also recommended is a water quality and streamflow monitoring program in Soda Butte Creek above and below the mill tailings pile.

SECTION 3

LEGAL FRAMEWORK

Authority

Montana statutory authority to conduct a feasibility study is found in Section 89-132, Revised Codes of Montana (R.C.M.) 1947. Subsections of that Section, among other things, broadly empower the Montana Department of Natural Resources and Conservation (DNRC):

> (d) To accept from any federal agency grants for and in aid of the carrying out of the purposes of this Act and any Acts of "Congress". . . .
>
> (t) To make investigations and surveys of natural resources and of opportunities for their conservation and development and pay the costs of the same either from its own funds or cooperatively with the federal government. . . .

The power of DNRC to enter into contracts for studies or investigations with the federal government is clear and has been utilized on numerous occasions for studies on different problem areas.

Site and Mineral Right Acquisition

The Montana DNRC has statutory authority to acquire the necessary sites for project construction. Section 89-104, R.C.M. 1947, provides the power to acquire by purchase, exchange, or condemnation "any land, rights, water rights, easements, franchises, and other property considered necessary for the construction, operation and maintenance of works." Section 89-102, R.C.M. 1947, defines "works" very broadly and includes therein "all means of conserving and distributing water," including those for purposes of "irrigation, flood prevention, drainage, fish and wildlife, recreation. . . ." Therefore, there is no question that DNRC has ample authority to acquire such sites as might become necessary for project construction.

SECTION 4

ENVIRONMENTAL INVENTORY

Cultural Environment

Mining History

The New World or Cooke City mining district, on the north boundary of Yellowstone National Park, has seen periodic mining activity from the late 1870's until the Nott mill at the Glengary mine was destroyed in 1967. Active mineral exploration and evaluation programs are being conducted in the Daisy Pass and Lulu Pass areas north of Cooke City, sites of previous surface and underground mining activities.

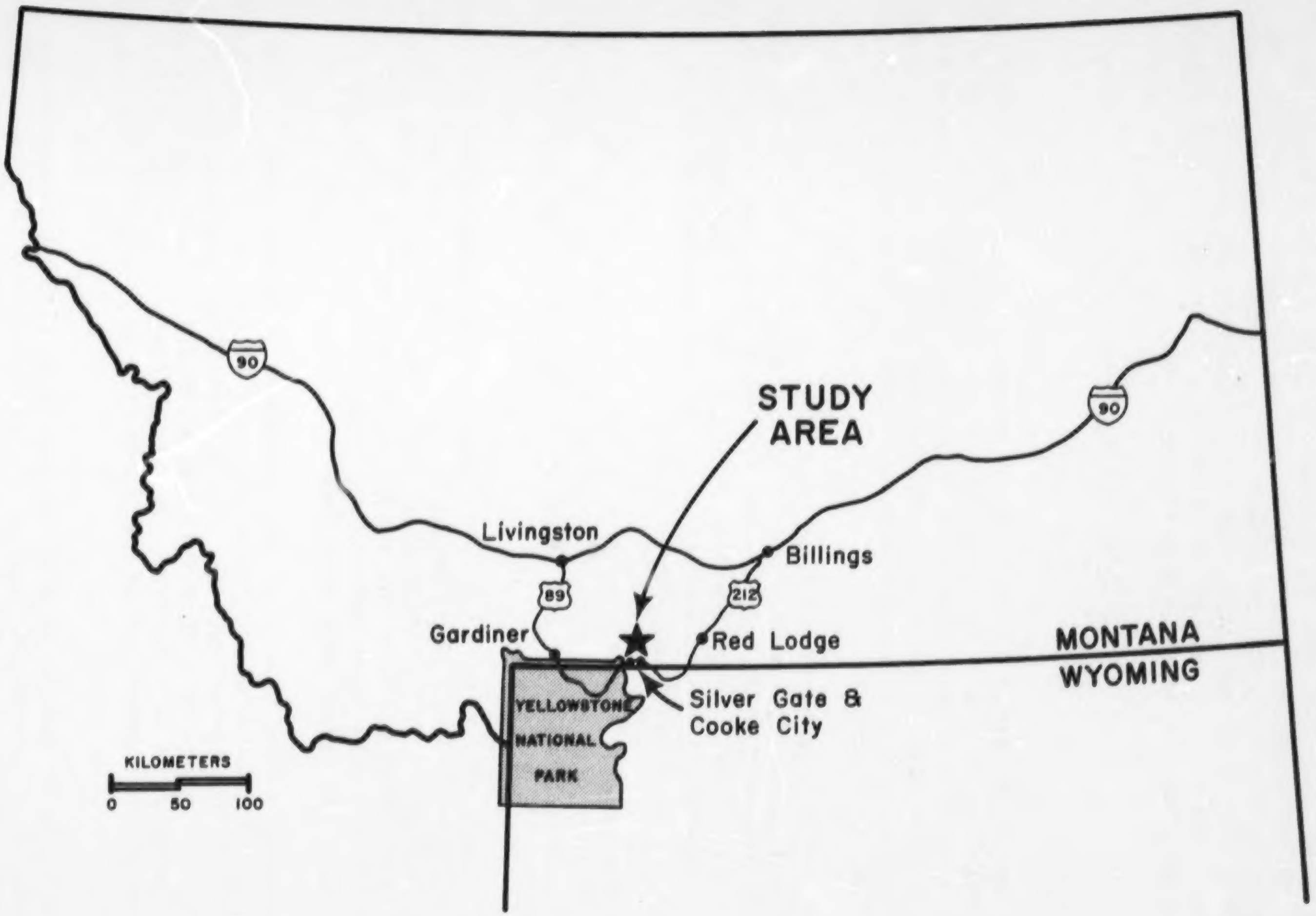
Current Social and Economic Conditions

The Cooke City acid mine project is located in Park County, Montana approximately 100 km southeast of Livingston, Montana (Figure 1, page 9). Portions of the project area lie within the Gallatin and Custer National Forests. Three mine areas were studied. The McLaren mine site lies within the Custer National Forest, while the Glengary mine and the McLaren mill site are in the Gallatin National Forest. Recreational areas within the national forest near the project area include three established camping grounds.

Yellowstone National Park is located approximately 6.4 km from Cooke City. U.S. Highway No. 212 passes through Cooke City to the northeast entrance to the Park. This highway brings many tourists that travel Interstate 90 to Yellowstone Park.

Recreation within the project area is limited to snowmobiling and cross-country skiing in the winter months. During the summer, recreation includes sightseeing, fishing, camping, and hiking.

The general economy of the area is based on tourism. During the summer months nearly all of the motels and hotels in Cooke City and Silver Gate are filled with tourists or retired people who spend the summer months in the area enjoying the cool climate and recreational opportunities that the area offers. In the winter months, most public facilities are closed with a few motels and cafes remaining open for those who use the area for winter sports.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Billings
Gardiner
Red Lodge
MONTANA
WYOMING
Silver Gate & Cooke City
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90
90
89
212
KILOMETERS
0
50
100

FIGURE I. Location of the study area.

Treatment of the AMD will probably not result in an increase in industrial activity or an increase in population due to better water quality. Yellowstone National Park and the National Forests are immediately downstream from the project areas, and their rules and regulations will prevent any increase in permanent population as well as any industry. However, removal of AMD will improve streams such that more kilometers are able to sustain fisheries. This in turn may result in an overall increase in use and may help to reduce the use of other overfished streams.

Physical Environment

Introduction

The New World mining district, which encompasses the three study sites of the Cooke City Acid Mine Drainage Control-Feasibility Study, lies on the southwest edge of the rugged Beartooth Mountains; the equally rugged Absaroka Range of Wyoming lies on the south. Yellowstone National Park is southwest of the district, and the Absaroka Range of Montana lies to the north and northwest of the district.

Valley floors range in altitude from 2,286 to 2,743 m, and numerous mountain peaks and ridges rise above 3,350 m. Glaciation has carved many characteristic U-shaped valleys and has left hanging valleys and cirque basins in many areas. Three drainage basins of the Yellowstone River system have their headwaters in the New World mining district, and each also includes one of the three study sites.

The McLaren mill tailings pond is on the east edge of Cooke City on Soda Butte Creek (Figure 2, page 11), which flows into the northeast corner of Yellowstone National Park and joins the Lamar River. The tailings pond is at about 2,317 m altitude.

The McLaren mine site, at an altitude of approximately 2,940 m on the southwest slope of Fisher (Red) Mountain, is in a part of the drainage that forms the headwaters of the Stillwater River. Daisy Creek, which begins near the mine area, flows westward for about 5 km before joining the Stillwater River, which then runs north through the proposed Absaroka-Beartooth Wilderness and joins the Yellowstone River near Big Timber, Montana.

The Glengary mine area is at the headwaters of Fisher Creek, which flows southeast about 8 km and joins with Lady of the Lake Creek to form the Clarks Fork Yellowstone River. The Clarks Fork flows southeast into the Sunlight Basin in Wyoming before swinging northward and eventually joining the Yellowstone River near Billings, Montana. The main Glengary adit is at 2,834 m, and the upper part of the study area is at about 2,987 m on Lulu Pass.

The climate is typical of mid-latitude, high altitude areas in the Rocky Mountains. Snow can be found at higher elevations throughout the year; several small glaciers and snow fields are found northeast of the district. Snow depths of 1,770 mm or more have been measured at Cooke City, and more

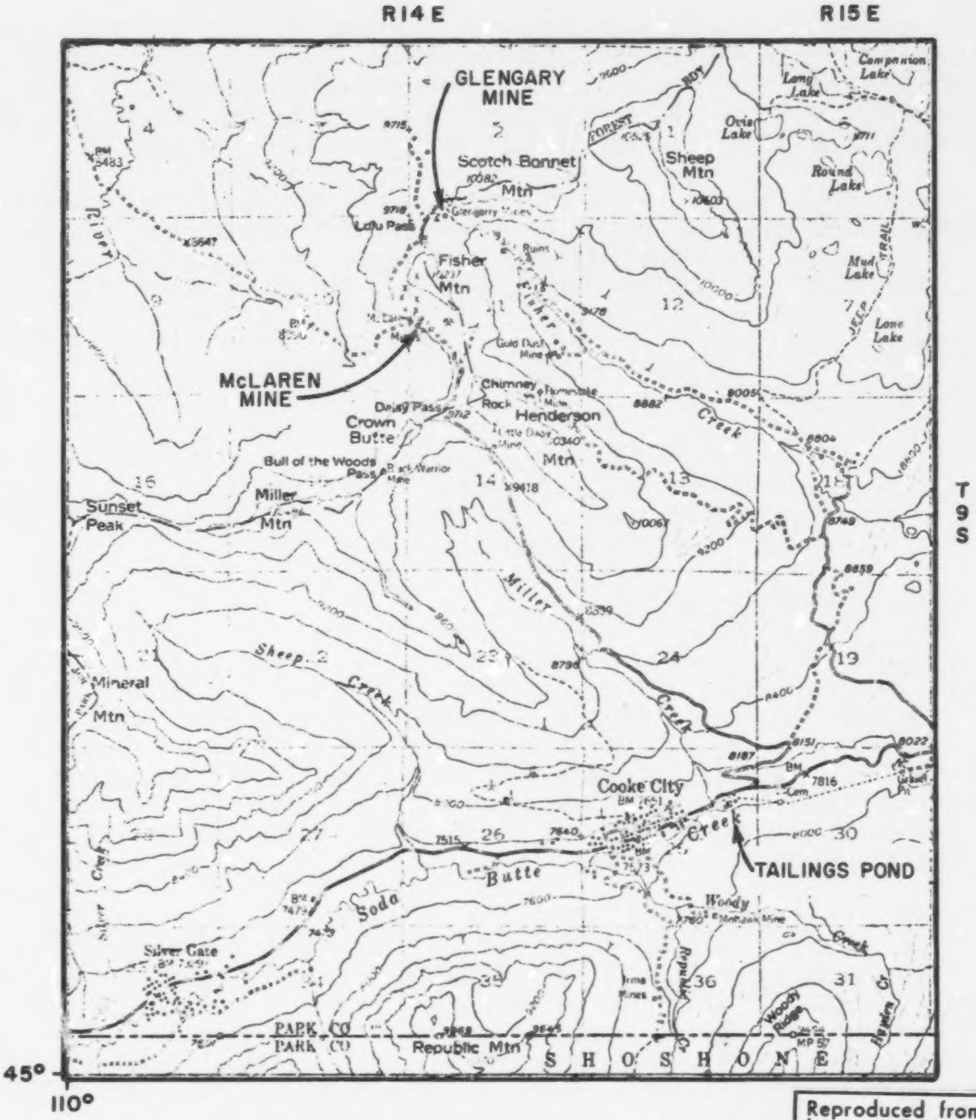
R14E
R15E
T 9 S
45°
110°
GLENGARY MINE
McLAREN MINE
TAILINGS POND
Scotch Bonnet Mtn
Sheep Mtn
Lulu Pass
Fisher Mtn
Crown Butte
Daisy Pass
Chimney Rock
Henderson Mtn
Bull of the Woods Pass
Miller Mtn
Sunset Peak
Mineral Mtn
Cooke City
Silver Gate
Republic Mtn
Long Lake
Companion Lake
Ovis Lake
Round Lake
Mud Lake
Lone Lake
Sheep Creek
Miller Creek
Fisher Creek
Soda Butte Creek
Woody Creek
Silver Creek
Republic Cr
Mohawk Mine
Irma Mines
Woody Ridge
PARK CO
SHOSHONE

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FIGURE 2 Location of the study area showing Cooke City, the McLaren and Glengary mine areas, and the McLaren mill tailings pond.

than 4,570 mm of snow has been measured in the areas above 2,940 m. Drifts of as much as 23 m have been reported (Lovering, 1929) in the pass areas around Cooke City.

The months of July through September provide ideal working weather, and the project areas are easily accessibile by two- and four-wheel drive vehicles over moderately rough roads. Snowmobiles provide the main means of transportation to the sites from Cooke City during most of the other months. The Cooke City-Gardiner highway is kept open throughout the year.

A mean annual precipitation of 675 mm and a mean annual temperature of 1°C are reported at Cooke City. Cooler temperatures and more precipitation (more than 1,500 mm) are encountered at the higher elevations of the mine sites. Precipitation data for the study period are presented in Appendix B.

Mine Areas

Introduction

The two mine areas studied, the McLaren mine, a predominately open pit operation and the Glengary mine (also known as the Como ore body), predominately an underground operation, are discussed in parallel fashion to better compare and contrast the factors affecting reclamation.

Physical Resources and Conditions

Location. The mines are located in sec. 2, 10, and 11, T. 9 S., R. 14 E., Park County, Montana. Both are within U.S. National Forests. The McLaren mine area, which drains into an unnamed tributary (informally called Daisy Creek in this report) of the Stillwater River, is at an altitude of 2,940 m and is in the Custer National Forest. The Glengary mine area, which drains into Fisher Creek, a tributary of the Clarks Fork Yellowstone River, is at an altitude of 2,970 m and is in the Gallatin National Forest. The locations of the mines are shown in Figure 2, page 11.

Metals Recovered, Ground Disturbed, and Exploration Holes Drilled. Both mines were primarily gold mines but yielded some copper and silver. The McLaren mine area encompasses approximately 8.1 hectares (ha), and an estimated 96,000 m^3 of material was disturbed or removed by mining. Underground workings were almost destroyed by the surface mining operations; one collapsed adit is still recognizable (sample site 108) just above the point where the road forks (Figure 3, page 13) and a minor amount of water is discharged from this adit.

The major disturbed areas at the Glengary mine area (Figure 4, page 14) on Lulu Pass cover about 3 ha; several smaller mine dumps are adjacent to the main disturbed area. Total volume of disturbed material is approximately 14,000 m^3, most resulting from very shallow trenching and mine-road construction. A significant portion of the disturbed volume came from the adits and drifts. At only two or three places do ore and waste materials have much depth. The site is drained principally by surface flows from the impoundment adjacent to the disturbed area and by a trench from the disturbed area.

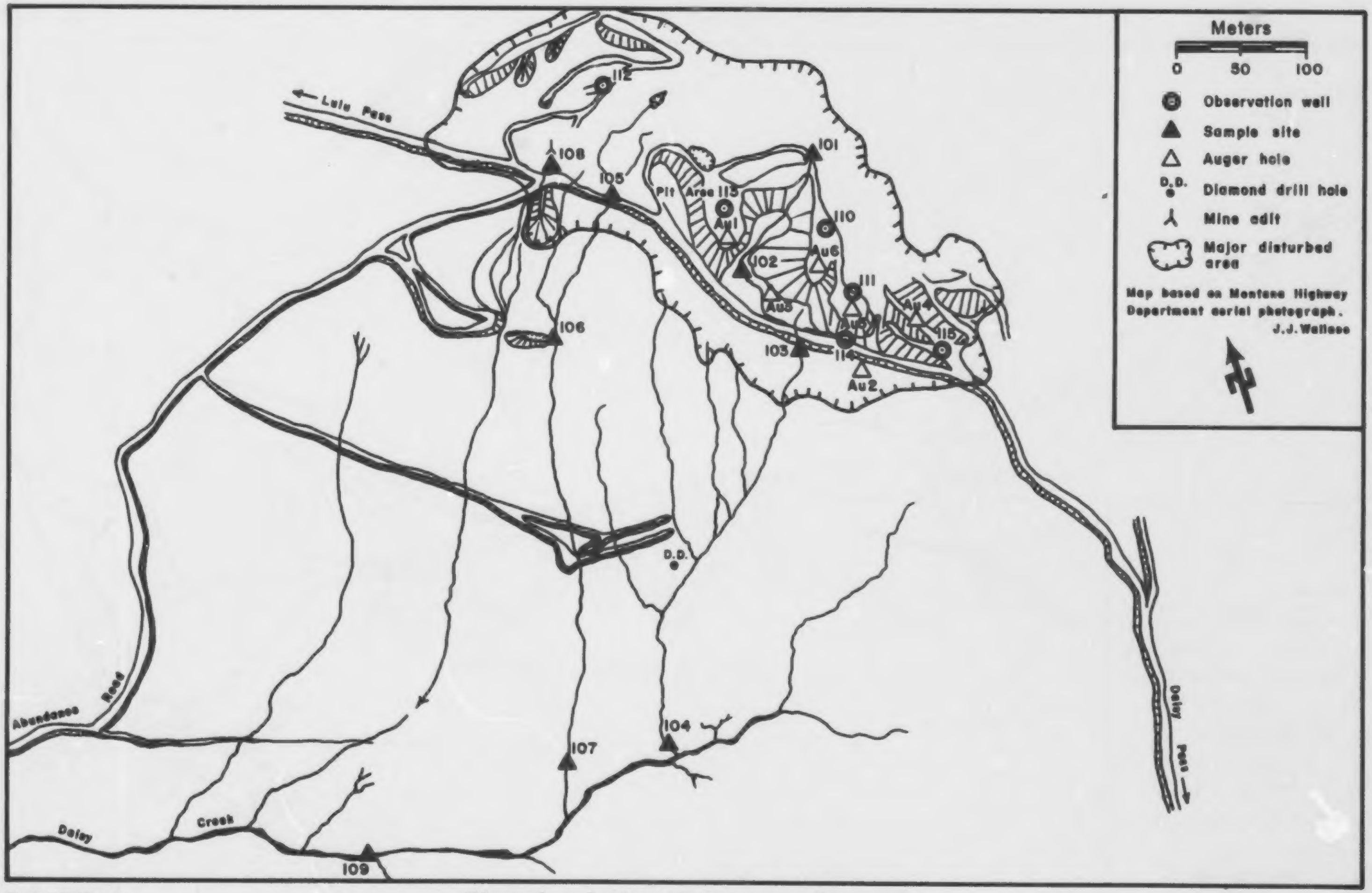

Meters
0
50
100
Observation well
Sample site
Auger hole
D.D.
Diamond drill hole
Mine adit
Major disturbed area
Map based on Montana Highway Department aerial photograph.
J.J. Wallace
← Lulu Pass
Daisy Pass →
Abundance Road
Daisy Creek
Pit Area
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
Au1
Au2
Au3
Au4
Au5
Au6
D.D.

FIGURE 3 Sketch of the McLaren mine area.

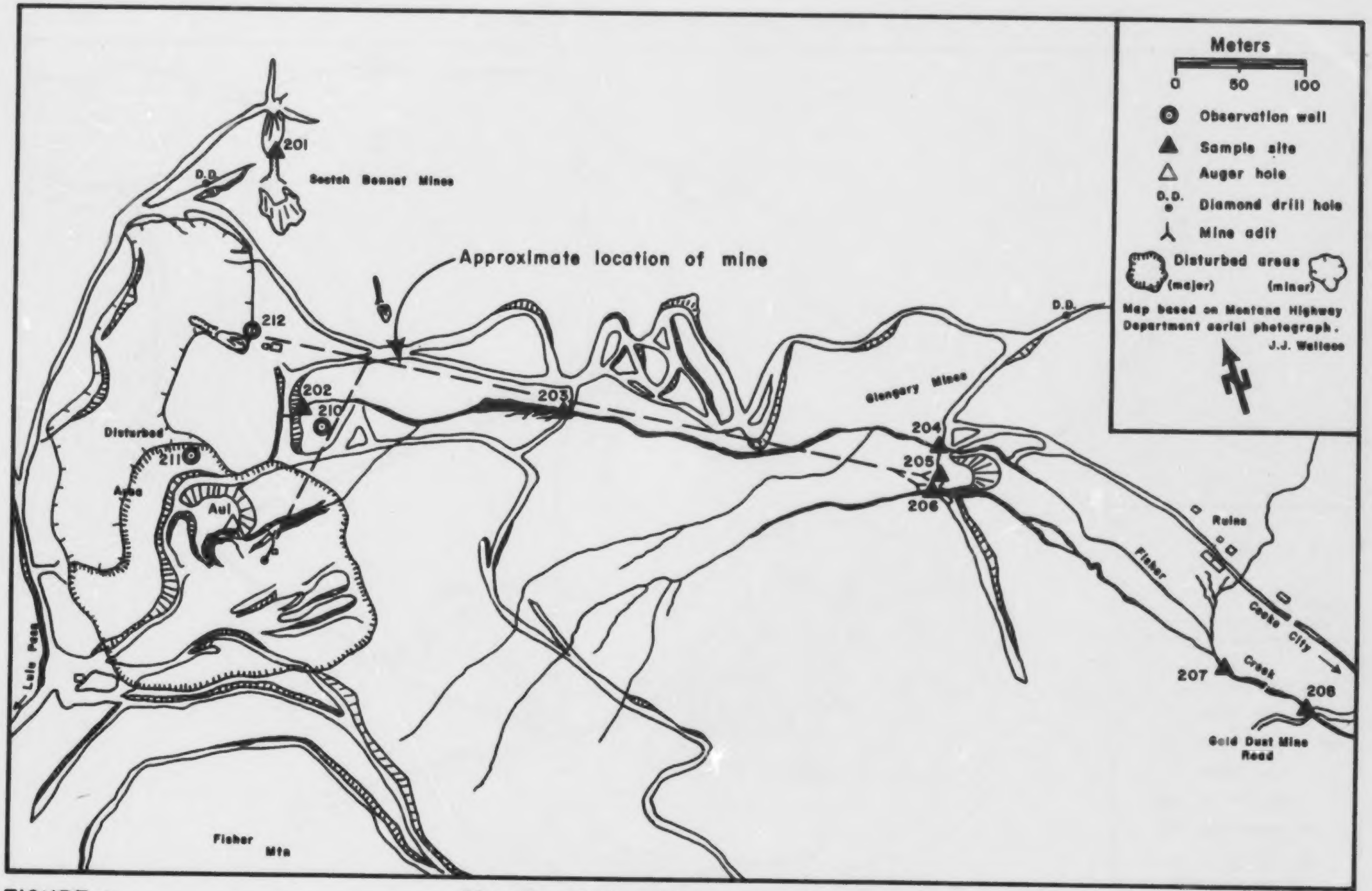

Meters
0
50
100
Observation well
Sample site
Auger hole
D.D.
Diamond drill hole
Mine adit
Disturbed areas
(major)
(minor)
Map based on Montana Highway Department aerial photograph.
J.J. Wallace
201
D.D.
Scotch Bonnet Mines
Approximate location of mine
212
202
210
203
Disturbed
211
Area
Aul
Glengary Mines
D.D.
204
205
206
Ruins
Fisher
Cooke City
Creek
207
208
Gold Dust Mine Road
Lulu Pass
Fisher Mtn

FIGURE 4

Sketch of the Glengary mine area.

The Scotch Bonnet adits have collapsed, and the amount of open workings behind the portals is unknown. The Glengary adit was mapped throughout its horizontal extent. The drift is predominantly 1.8 m wide and 2.1 m high, requiring the removal of approximately 3,000 m^3 of waste material. Part of this volume is replaced by unconsolidated iron hydroxide precipitates whose density is estimated at 1.5 grams/cubic centimeters; roughly 400 m^3 of this material is present, predominantly in the lower 300 m of the drift. A map showing the drift and the major zones of water leakage is presented in Figure 5, page 16. The water-inflow estimates are valid only for the late fall conditions. A greater percentage of the water may come through the manways (raises) during the spring runoff period.

The mining areas have been drilled by at least two exploration companies (Bear Creek Exploration and Mine Finders Incorporated). The locations and depths of the holes were not released by the companies, but the locations of all drill holes noted during this study are marked on the site maps. Active mining is not foreseen in the near future for either of these areas. The Como ore body does contain reasonable metal values and might be mined at some future date. The biggest drawback to mining in this area is haulage cost. A new mill would have to be built, and concentrate would have to be hauled to Red Lodge, as the Gardiner spur of the Burlington Northern Railroad has been shut down.

Geology

Introduction. The geology of southwest part of the Cooke City quadrangle was mapped by James Elliott (1973) during the four summers from 1969 through 1972. A preliminary field check of Elliott's map was in agreement with all major features. Due to limited field time, emphasis was placed upon the overall relationships between Tertiary felsite intrusive breccia and the occurrence of sulfide mineralization while stratigraphic contacts of specific Cambrian formations, and petrologic variations of the Tertiary igneous units were not emphasized.

The geologic map presented (Figure 6, page 17) is based upon Elliott's map with minor changes. More important to this investigation is the fact that the sulfide mineralization is concentrated along the contact of intrusive breccia with carbonate country rock. The sulfide concentrations are the result of hydrothermal interaction and are greatest in the country rock adjacent to the intrusive breccia, decreasing in both directions away from the contact.

McLaren Mine. The McLaren property is on the southwestern side of Fisher Mountain where the Park Shale and Meagher Limestone are believed to be in contact with the felsitic breccia. Small sills of the breccia may be found in roadcuts and in the mining face, where breccia has intruded along and across bedding planes in the Park Shale. Field evidence for contact between the felsite breccia and predominantly carbonate (basal Park Shale or upper Meagher Limestone) units is sparse; but: (1) northwest of the mine area a ditch exposes weathered felsite and a reddish-brown residual soil believed to have developed on limestone, and (2) in the trail switchback, just above the northwestern end of the mine area, the breccia sills intrude

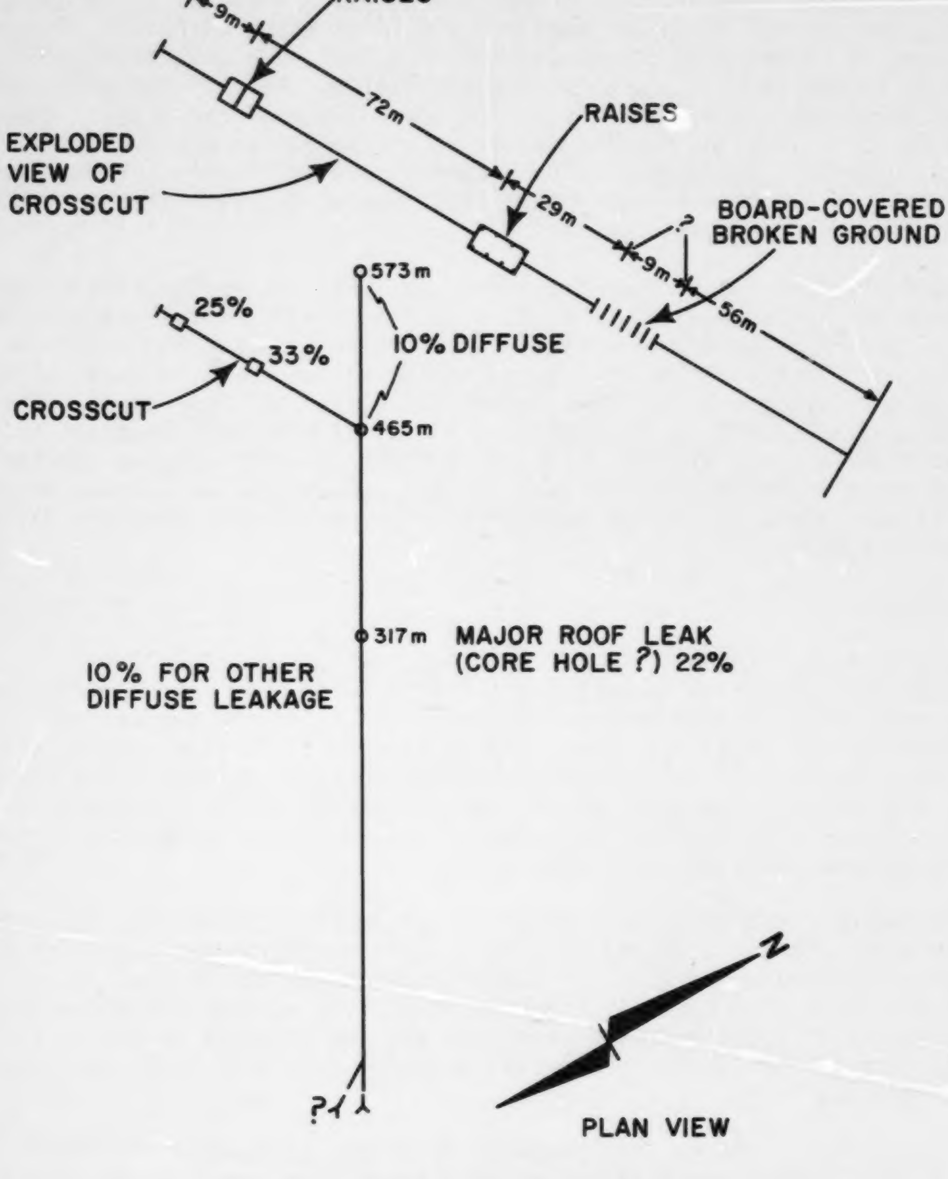

RAISES
9m
72m
RAISES
EXPLODED
VIEW OF
CROSSCUT
29m
?
BOARD-COVERED
BROKEN GROUND
9m
56m
573m
25%
10% DIFFUSE
33%
CROSSCUT
465m
317m
MAJOR ROOF LEAK
(CORE HOLE ?) 22%
10% FOR OTHER
DIFFUSE LEAKAGE
?
N
PLAN VIEW
SCALE
0 METERS 100

FIGURE 5 **Relative percentage of water in the lower Glengary tunnel.**

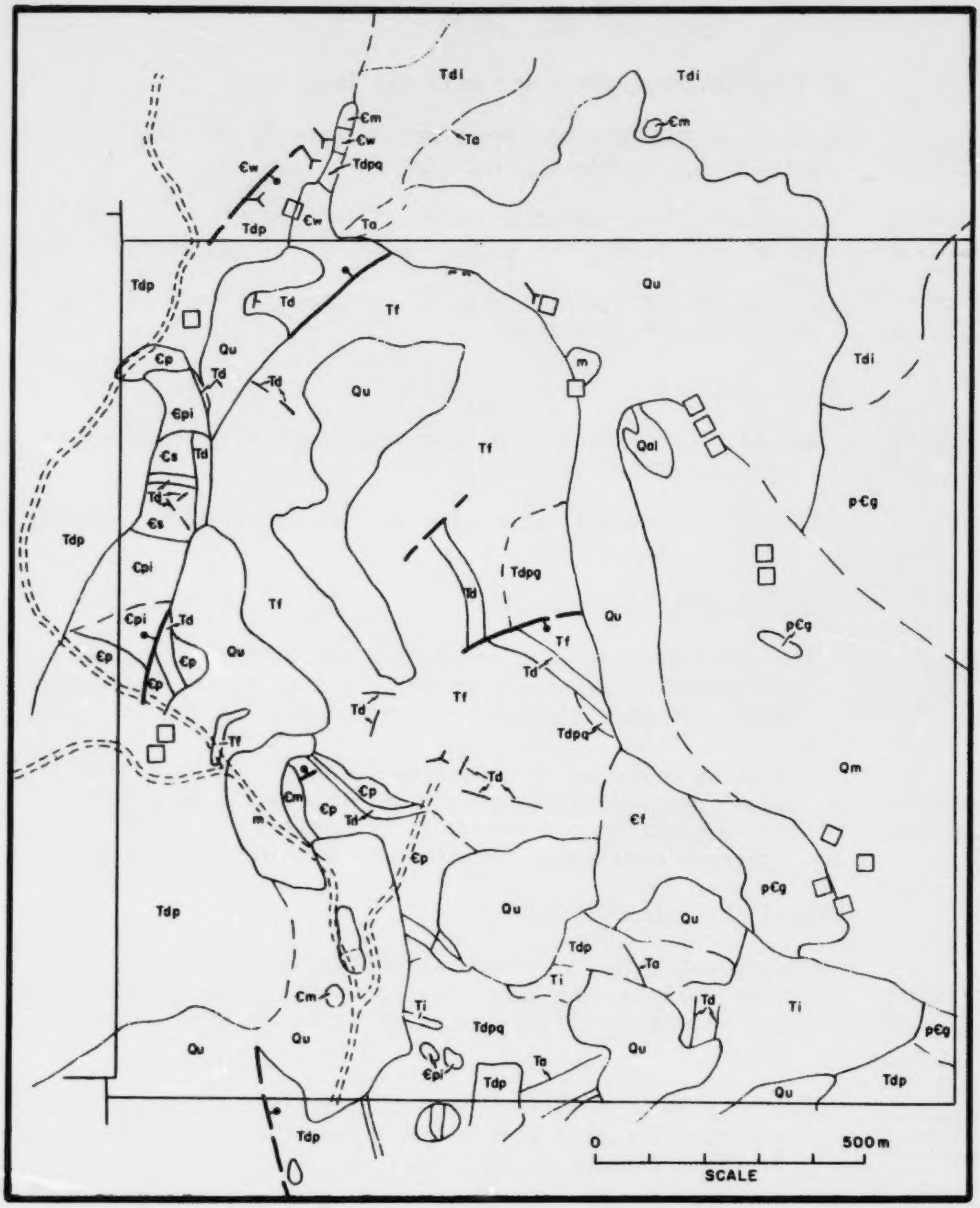

Tdi
Tdi
€m
€w
Ta
€m
€w
Tdpq
Tdp
€w
Ta
Tdp
Td
Tf
Qu
Qu
€p
Td
Td
€pi
Qu
m
Tdi
€s
Td
Qal
Tf
Td
€s
p€g
Tdp
€pi
Tdpq
Td
€pi
Td
Tf
Qu
p€g
€p
€p
Qu
Td
€p
Tf
Td
Tdpq
Tf
Td
Qm
€m
€p
€p
Td
m
€f
€p
Tdp
Qu
p€g
Qu
Tdp
Ta
Ti
€m
Ti
Ti
Td
Tdpq
p€g
Qu
Qu
Qu
€pi
Ta
Tdp
Tdp
Qu
Tdp
0
500m
SCALE

FIGURE 6 Geologic map of sec. 11 and part of sec. 2, T. 9 S., R. 14 E., near Cooke City, Montana, after Elliott (1973).

KEY TO FIGURE 6

(Elliott, 1973)

m	MINE WASTE--Mine dumps and mill tailings
Qal	ALLUVIUM (HOLOCENE)--Unconsolidated deposits of silt, sand, gravel, and boulders along stream valleys
Qu	UNDIFFERENTIATED SURFICIAL DEPOSITS (HOLOCENE)--Principally talus, colluvium, and glacial deposits of neoglacial origin
Qm	MORAINAL DEPOSITS (PLEISTOCENE)--Till and fluvioglacial deposits undifferentiated
	DIKES (EOCENE)
Ta	Andesite, trachyandesite, and basalt--Usually porphyritic with aphanitic groundmass
Td	Dacite--Porphyritic with fine-grained to aphanitic groundmass
	INTRUSIVE BRECCIAS (EOCENE)
Tf	Felsite intrusive breccia--Mostly monolithologic, altered, pyritized, aphanitic complex on Fisher Mountain, locally weakly porphyritic with altered plagioclase phenocrysts
Ti	Intrusive breccias on Henderson Mountain--Heterolithologic with igneous fragments ranging from dacite to andesite in composition and fragments of Precambrian gneiss and Cambrian sediments, locally much altered and mineralized
	STOCKS AND SILLS (EOCENE)
Tdi	Diorite--Stocks and irregular bodies, mostly equigranular, fine grained, and dark colored, plagioclase and pyroxene are dominant. Sills laccolith, and irregular-shaped masses
Tdp	Dacite porphyry--Fine grained to aphanitic groundmass, light colored, variable alteration, plagioclase, hornblende and/or biotite phenocrysts common

Tdpq	Dacite porphyry with quartz "eyes"--Similar to dacite porphyry (Tdp) but with abundant rounded quartz phenocrysts
Tap	Andesite porphyry--Principally in sills, light to medium green, much altered, plagioclase, clinopyroxene and/or hornblende phenocrysts common

SEDIMENTARY ROCKS (CAMBRIAN)

€s	Snow Range Formation (upper Cambrian)--Shale, limestone--pebble conglomerate, limestone and dolomite, thin bedded, includes Grove Creek Member at top approximately 70 m in thickness
€pi	Pilgrim Limestone (upper Cambrian)--Limestone and limestone-pebble conglomerate, thick bedded, approximately 76 m in thickness
€p	Park Shale (middle Cambrian)--Shale and limestone, thin bedded, approximately 76 m in thickness
€m	Meagher Limestone (middle Cambrian)--Limestone, thin bedded, approximately 30 m in thickness
€w	Wolsey Shale (middle Cambrian)--Shale and sandstone, thin bedded, approximately 55 m in thickness
€f	Flathead Sandstone (middle Cambrian)--Sandstone, medium bedded, approximately 30 m in thickness

PRECAMBRIAN METASEDIMENTS

p€g	Granitic rocks (PRECAMBRIAN W)--Mainly granitic gneiss, minor schist, amphibolite, and quartzite, weakly to strongly foliated

Contact--Dashed where approximately located; short dashed where inferred

Fault--Dashed where approximately located; short dashed where inferred; dotted where concealed. Ball and bar on downthrown side

20

Strike and dip of inclined beds

limestone, which may or may not be in place. The main wall of the mine contains altered limestone beds affected by both dikes and sills of felsite and "andesite" (possibly dacite), which are offset by thin sulfide-filled fault zones showing minor displacement (less than 0.3 m in most places). Most of the intrusive rocks within the mined area are altered by the hydrothermal solutions.

Two types of hydrothermal alteration were recognized at the mine. The product of propylitic alteration, as used in this report, consists predominantly of chlorite, but minor epidote or calcite is locally present; it is always associated with magnetite and pyrite in varying amounts. Argillic alteration produces a mixture of kaolinite and montmorillonite and minor amounts of chlorite or quartz. At the McLaren, the arquillic alteration may be easily traced because the bleaching effect (argillic zones are dirty beige to off-white) contrasts vividly with the reddish-brown hematitic staining of the propylitic alteration zone. The offsets and bulbous shapes of these two alteration zones indicate areas of post-mineralization faulting and of local variation of mineralogy or porosity within the host rock.

Sulfide minerals seen on the surface at the McLaren mine are concentrated in the proplitic alteration zone. Pyritic replacement bodies seem to be restricted to the carbonate layers within the Park Shale, whereas pervasive but disseminated sulfide minerals characterize the propylitized shale. In contrast, the exposed argillic alteration zone contains very sparse sulfide minerals.

Glengary Mine. The Glengary area is at the north end of Fisher Mountain, just below Lulu Pass, and on the eastern end of Scotch Bonnet Mountain. Much of the ground has been disturbed (Photo 1 and Figure 4, pages 21 and 14). The adit (collapsed) into Fisher Mountain above the old cabin (Photo 2, page 22) (Como ore body) followed hydrothermal veins within the Cambrian limestone. The mineralization differs from that described at the McLaren in that copper seems to predominate. Iron staining is far less intense than at the McLaren, and the copper minerals malachite and azurite were noted as coatings and encrustations on blocks of rubble below the adit.

The two adits (collapsed) that were driven northward into the eastern nose of Scotch Bonnet Mountain follow a zone of hydrothermal alteration. The alteration is very intense, and the Cambrian sedimentary rocks mapped by Elliott (1973) were not recognized, but they probably extend west of the zone of alteration, as well as being the altered country rock. This intensely altered area is of particular geologic interest because the dacite porphyry, which crops out west of the diorite of Scotch Bonnet Mountain, shows "crackle" texture near the contact with the diorite. No xenoliths of either rock type were found within the other rock type, but the "crackle" texture suggests that the porphyry was intruded after the diorite float adjacent to the propylitic zone shows only minor evidence (chlorite and epidote (?)) of hydrothermal alteration. No evidence of alteration was found in the porphyry outcrop. The dumped material below the adits is very pyritic and appears similar to the mineralized rock at the McLaren mine.

Photo 1. Upper Glengary mine area showing disturbed area.

Photo 2. Upper Glengary mine area showing collapsed mine adit.

The Tertiary dacite, mapped by Elliott (1973) as being in fault contact with the felsite breccia, was not noted during the geologic investigation. The drift from the lower Glengary tunnel passes through about 460 m of felsite before the boundary with diorite is reached. The diorite (field identification by mine lamp) may be Elliott's dacite or the Scotch Bonnet diorite, but the presence of mafic phenocrysts (amphiboles (?)) and fairly coarse texture led to the diorite identification. The contact between the felsite and the diorite was not observed, probably because it is obscured by the goethitic coating on the mine walls. Within the diorite, a shear zone filled with chlorite and hydrothermal biotite was encountered just before the eight-post raise (Figure 5, page 16). Minor sulfide minerals are present in both mineral phases of the shear zone.

The disturbed area below Lulu Pass (Photo 1, page 21) contains several erosional cuts through zones of argillic alteration. The clays have a blue-grey hue caused by finely disseminated sulfide minerals. This is a definite contrast to the near absence of sulfide minerals in the zone of argillic alteration at the McLaren mine.

Hydrology

Introduction. Weather conditions at the higher elevations of the McLaren and Glengary mine areas precluded installation of observation wells and gauging stations and general reconnaissance of the areas until late July and August 1974. One field trip in September 1974 was cut short by an early fall snow storm, and field work was suspended, although visits to the stream and observation-well sites for sample collection and streamflow measurements continued. The heavy spring snows and near-record snowpack in 1975 resulted in atypical runoff conditions.

The principal source of water flowing through or over the disturbed areas of the McLaren and Glengary mines is snowmelt. Rainfall contributes a small amount during the summer months, but no continuous records are available for the areas at this time. Precipitation, including snowfall, at the higher elevations of the mine areas is greater than that measured at Cooke City.

McLaren Mine. The McLaren mine area (Figure 3, page 13) includes approximately 8.1 ha, and about 96,000 m^3 of disturbed material (Photo 3, page 24) cover the area. Dumps and waste piles form a hummocky topography in the area. The site is drained by surface flows and seepage through the disturbed areas.

Recharge by snowmelt infiltration above the McLaren mine area is probably not enough to support a year-round groundwater flow at the mine area. At site 101 (Figure 3, page 13), at the base of the back wall at the disturbed area, is a flow that is believed to come from a fracture or joint system in the bedrock. (The bedrock is covered by talus material.) This flow and the flow at site 105 were the first to go dry (Table 1, page 25), indicating that the groundwater supply above the mine area had been depleted. The surface sites went dry approximately two months after the last snowbanks above the sites had melted. Sites 102, 103, 104, and 107 were dry by

Photo 3. McLaren mine area showing disturbed area.

TABLE 1. McLAREN MINE AREA STREAMFLOW DATA (lps)

	Site no. (see Figure 3)							
Date	101	102	103	104	105	107	108	109
07/25/74	.7	6.2	--[a]	29.2	2.8	6.2	.6	92.6
08/13/74	.3	1.7	--	3.7	.6	2.0	.1	29.7
09/16/74	< .1	--	--	.9	.1	.3	.3	6.5
10/15/74	d[b]	.4	4.5	1.2	d	.3	.5	4.5
11/19/74	d	d	d	d	d	u[c]	.1	2.2
01/23/75	d	d	d	s[d]	d	u	s	2.2
02/18/75	d	d	--	s	d	s	s	2.2
05/15/75	d	d	d	s	d	s	s	6.0
05/28/75	--	--	--	--	--	--	--	6.0
06/07/75	s	s	s	s	s	s	s	56.9
06/12/75	--	--	--	--	--	--	--	31.7
06/18/75	s	s	s	s	s	s	s	47.6
07/01/75	--	--	--	--	--	--	--	173.0
07/18/75	--	2.8	5.7	12.2	--	--	2.3	166.0
07/31/75	.3	2.8	4.0	6.5	2.3	3.1	1.4	51.6
08/05/75	.6	1.4	2.3	5.1	.6	.9	.6	33.4
08/12/75	.5	1.4	1.7	2.3	.2	1.7	.5	18.1
08/20/75	.3	.9	.9	1.7	u	.6	.3	18.1
08/27/75	.1	.6	.9	.9	u	1.1	.9	11.9
09/05/75	u	.4	1.1	1.1	u	.6	.4	9.1
09/09/75	u	.3	.6	1.4	u	.3	.3	9.1
09/23/75	u	.3	--	.3	u	u	.3	5.1

[a] Dash indicates no record
[b] d indicates dry
[c] u indicates unmeasurable small flow
[d] s indicates snow covered

November 1974, indicating further depletion of the groundwater supply and a lowering of the water table in these areas.

The hydrology of the disturbed area seems to be complex. As reported by Higgins (1974), some of the surface areas seem to be slightly sealed by clay formed by physical disintegration and chemical weathering of the material. This is especially true in some depressions, which tend to fill with water from the melting snow. Infiltration into the spoils from these ponds seems to be relatively slow. The largest depression between sites 101 and 102 had a surface outflow, although another depression about 100 m north of site 102 did not have a surface outflow. The latter depression went dry about the same time that the snow melted from it, suggesting that infiltration rates nearly matched the snowmelt rates.

Five of the six observation wells in the disturbed area were relatively dry when installed and have remained dry. Auger holes drilled for spoils samples (Figure 3, page 13) in September 1975 did not encounter water. This suggests that there is a seasonal flow of water through the wastes at those sites. If a water table is established in the wastes, it is probably a shallow, fast-moving groundwater system that coincides with the duration of the snowmelt and drains completely out of the upper 5 m of the spoils material soon after the snow is all melted.

Well 110, about 55 m south of site 101, was dug to apparent bedrock, and water was encountered in that hole. Between August and November, a definite decline in the water level was noted (Table 2, page 27), suggesting that the well water level was in equilibrium with a water table, possibly a perched water table of small extent. The water at site 110 could also be coming from a fracture system in the bedrock beneath the waste material. The surface sites downslope from site 110 dried up before the observation hole, indicating that the water is returning to deep fractures in the bedrock instead of following the bedrock surface to the seep sites.

A driller on a minerals-exploration diamond drill rig in the area reported that the first several hundred meters of rock were intensely fractured. This would suggest that as the groundwater supply declines, the water would probably go deeper, following the fracture systems in the bedrock, reappearing only as the stream base-flow contribution or as seeps adjacent to Daisy Creek.

A schematic representation of the thickness of unconsolidated material from the mine wall to the creek is presented in Figure 7, page 28. The water released by snowmelt is believed to follow time-dependent paths. Winter and spring melt waters provide a small amount of surface runoff and recharge the groundwater reservoir, which consists of: (1) the unconsolidated material, and (2) the joints and fractures in the igneous and sedimentary rocks. The big summer snowmelt is almost entirely runoff, although surface storage occurs within all closed depressions. At the end of the snowmelt period, discharging groundwater released from storage in the spoils and bedrock appears at the surface as seeps and rivulets located: (1) near the ponds in the spoils area, (2) along the portions of the uncovered zone of

TABLE 2. McLAREN MINE OBSERVATION WELL, NO. 110[a]

Date	Depth to water (m)
08/13/74	2.94
09/16/74	3.38
10/15/74	3.50
11/19/74	3.61
01/23/75	s[b]
02/18/75	s
05/15/75	s
05/28/75	s
06/07/75	s
06/12/75	s
06/18/75	--[c]
07/01/75	--
07/18/75	3.12
07/31/75	3.20
08/05/75	3.28
08/12/75	3.36
08/20/75	3.40
08/27/75	3.49
09/05/75	3.56
09/09/75	3.59
09/23/75	3.60

[a] Wells 111 through 115 remained dry
[b] s indicates snow covered
[c] Dash indicates no record

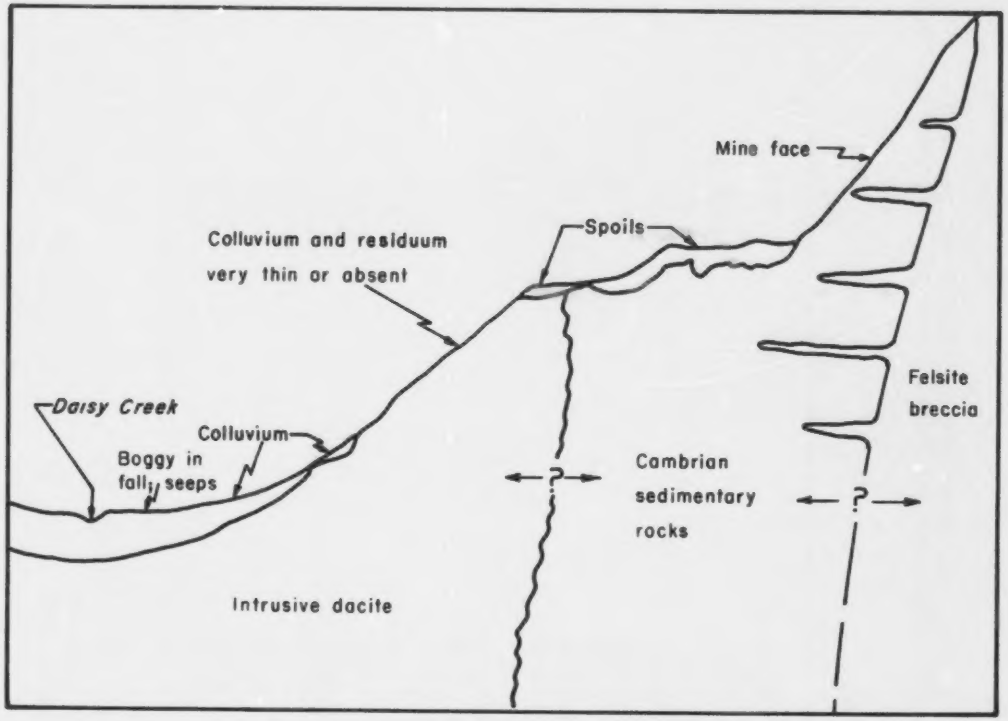

Mine face
Spoils
Colluvium and residuum very thin or absent
Daisy Creek
Colluvium
Boggy in fall, seeps
Felsite breccia
?
Cambrian sedimentary rocks
?
Intrusive dacite

FIGURE 7 Schematic cross section showing the thickness of unconsolidated deposits at the McLaren mine area.

the dacite porphyry, and (3) within the lower part of the colluvium. Toward the end of summer, visible seepage in the spoils area and the upper part of the exposed dacite disappears. The seepage continues in the lower part of the exposed dacite for longer than would be expected, based upon comparisons with "similar" topographic settings nearby. This is believed to result from the accumulation of ferric hydroxide crust upon the bedrock, which probably retards the discharge of groundwater stored within the fractured dacite. By fall, groundwater storage has declined, and the water table within the dacite no longer intersects the land surface; groundwater discharge is essentially restricted to the colluvial areas near the stream channel. The boggy areas result from decreased permeability in the vicinity of the stream channel; the permeability decrease is attributed both to the finer size of colluvial material as the distance from its source increases and the drainage gradient decreases, and to the buildup of hydroxide precipitates within and adjacent to the streambed.

The hydrograph for Daisy Creek at the weir (site 109) is presented in Figure 8, page 30, for the period of record. The drainage area is approximately 0.9 km^2 and recorded flows range from 2.2 to 173 liters per second (lps). The estimated peak flow at this station was 270 lps on July 10, 1975. The stream characteristics seem to be fairly typical of small subalpine watersheds in mountainous areas.

Snow cores were collected with the aid of the Soil Conservation Service's Snow Survey Supervisor, Phillip E. Farnes, on May 14, 1975. Two samples were taken on the McLaren site, by the cabin at the fork in the road (Lake Abundance turnoff), and one up on the open pit bench, roughly 5 m from the face. The cores contained 1,158 and 1,181 mm of water equivalent (after 10 percent reduction for the shape of the cutting device), and the snowpack depths were 2,730 and 2,770 mm respectively. The average annual streamflow at site 109 was estimated to be slightly more than 0.50 cubic hectometers per year, and annual precipitation should be on the order of 1,800 to 2,000 mm per year, of which roughly two-thirds is snow. Precipitation at the mine site should be approximately three times greater than that recorded at Cooke City.

Glengary Mine. The major disturbed areas at the Glengary mine (Figure 4 and Photo 1, pages 14 and 21) on Lulu Pass cover about 3.0 ha; several smaller mine dumps are adjacent to the main disturbed area. Total volume of disturbed material is approximately 14,000 m^3. Most of the disturbed surface has resulted from very shallow trenching and mine-road construction. At only two or three places do ore and waste materials have much depth. The upper mining area is drained principally by surface flows from the impoundment adjacent to the disturbed area and by a trench from the disturbed area. A water level (Table 3, page 31) was established in well 210 (Figure 4, page 14), indicating that a water table exists in that area at shallow depth, at least during the part of the year when the well could be found. Seeps occur downslope from the well and flow into the main drainage from the area (sites 204 and 206). Disturbed ground near the lower adit includes deposits of iron oxide precipitates at the mouth of the adit (site 205), a main dump having a volume of about 7,300 m^3, and the remains of settling ponds below the old mill site.

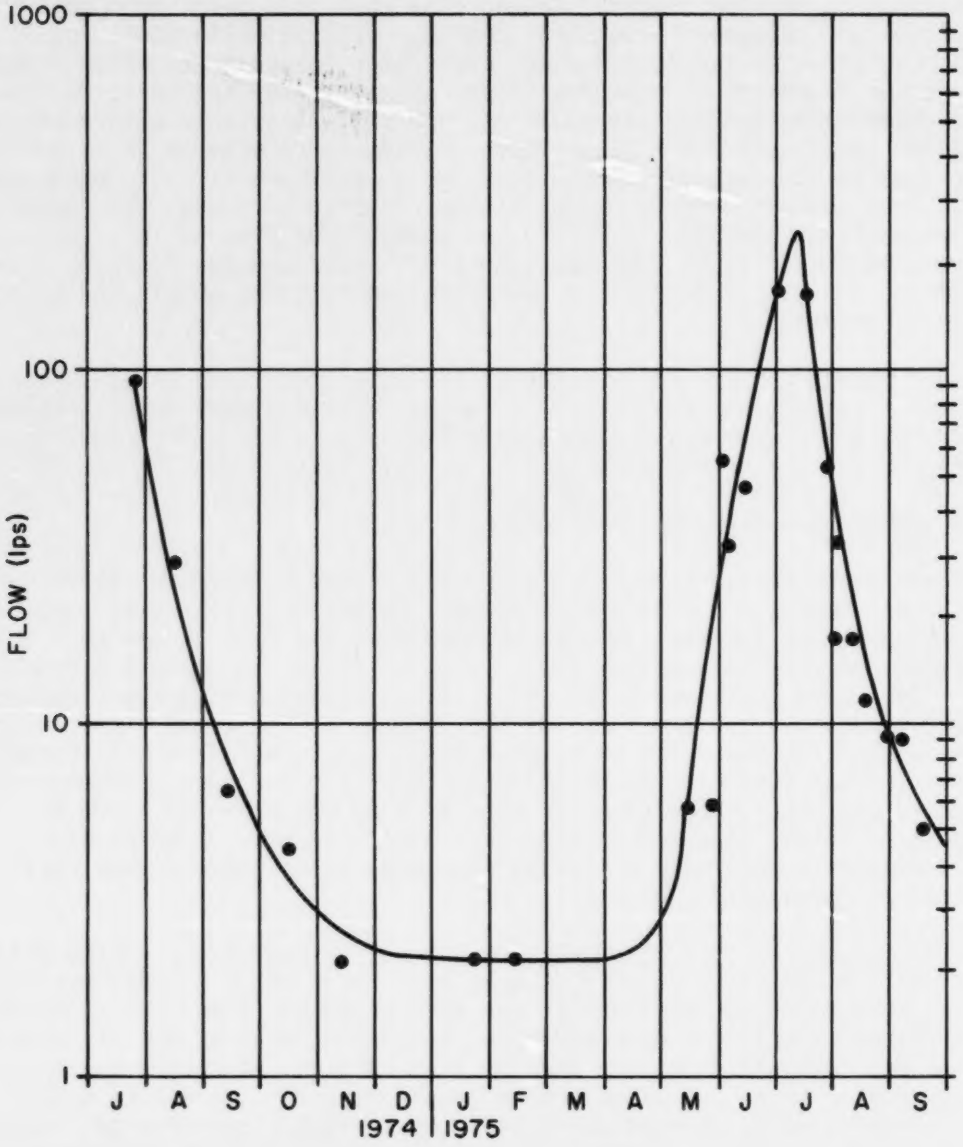


FIGURE 8 Hydrograph for Daisy Creek at site 109, McLaren mine area.

TABLE 3. GLENGARY MINE OBSERVATION WELLS

Date	Depth to water (m) for well no. 210	211	212
09/16/74	1.36	d[a]	d
10/14/74	1.76	--[b]	--
05/14/75[c]	d	d	d
05/28/75	--	--	--
06/07/75	--	--	--
06/12/75	--	--	--
06/18/75	--	--	--
06/22/75	1.41	0.88	--
07/01/75	1.32	0.55	--
07/19/75	1.36	0.46	1.25
08/01/75	1.42	0.72	1.48
08/05/75	1.45	1.03	1.51
08/12/75	1.43	1.54	1.52
08/20/75	1.42	2.04	1.55
08/27/75	1.41	2.33	1.61
09/06/75	1.41	d	1.64
09/09/75	1.41	d	1.64
09/23/75	1.51	d	d

[a] d indicates dry well
[b] Dash indicates no record
[c] November 1974 through April 1975; all three wells remained dry

The head of Fisher Creek, at the upper workings, is bowl-shaped and may be of glacial origin. A small pond in the base of the bowl collects meltwater in the spring and summer. It is believed that this ground is never frozen in the winter and that it is a major entry point for meltwater into the groundwater system. Snowmelt and precipitation contribute enough water to the bedrock groundwater system to cause a fairly constant outflow from the lower Glengary adit (site 205) as shown in Table 4, page 31.

The lower Glengary drift was mapped. The results of this survey are shown in Figure 5, page 16. The drift is very well preserved considering that it was driven in the early 1930's. Large deposits of iron precipitates are present on the floor, especially closer to the adit. Major sources of water infow are the raises (over half of flow), which probably interconnected with the surface, and a major roof leak at 312 m. The underground workings act as collectors and conduits to discharge the groundwater at the adit (Figure 5, page 16). The formations in the raises are reported to be extensively fractured, with seepage occurring along most of the raises.

The zones of water inflow, discussed in the geology section, are believed to be one of the major pathways for groundwater discharge from the area below Lulu Pass. A second pathway, groundwater flow through the unconsolidated Quaternary materials, must also be considered. The greatest amount of water probably moves through the gravel underlying the stream channel (often referred to as underflow). It is difficult to measure underflow, and such studies were judged to be beyond the scope and budget of this program. It is believed that the annual groundwater flow through the unconsolidated materials from the upper workings to the lower adit consitutes less than 20 percent of the annual surface water flow.

The hydrograph for Fisher Creek at the weir site (site 207) is presented in Figure 9, page 34, for the period of record. The drainage area is approximately 1.3 km^2, and recorded flows range from 3.1 to 283 lps. The estimated peak flow at this station was approximately 420 lps on July 5, 1975. The stream characteristics seem to be fairly typical of small subalpine watersheds in mountainous areas.

Snow cores were collected as described previously. Water equivalents ranged from 899 mm at the head of the bowl (cirque) to 1,670 mm near the creek at the altitude of site 205. The two samples in the upper disturbed area averaged 955 mm of water, and the sample at the weir contained 1,180 mm of water. Actual snowfall and total annual precipitation in the study area of Fisher Creek may be somewhat greater than at the McLaren site, owing to its slightly higher altitude and leeward position with respect to the prevailing winds. Precipitation data collected by the Soil Conservation Service at their Fisher Creek gauging station (altitude roughly 2,700 m) averaged 1,670 mm annually for an eight-year period of record; these data are presented in Table 5, page 35.

TABLE 4. FISHER CREEK AREA STREAMFLOW DATA (lps)

Date	Site no. 201	202	203	204	205	206	207
07/26/74	--[a]	--	--	--	--	--	96.3
09/16/74	u[b]	u	.2	.5	3.5	.2	12.2
10/14/74	d[c]	d	d	d	2.2	.5	8.5
11/20/74	d	d	d	d	2.2	d	4.4
12/18/74	d	d	d	d	s[d]	d	4.5
01/22/75	d	d	d	d	s	d	3.1
02/04/75	d	d	d	d	2.3	d	3.1
02/18/75	d	d	d	d	s	d	3.1
03/20/75	d	d	d	d	s	d	3.1
04/15/75	d	d	d	d	s	d	3.1
05/14/75	d	d	d	d	1.2	d	12.2
05/28/75	--	--	--	--	--	--	8.8
06/07/75	--	--	--	--	--	--	24.6
06/12/75	--	--	--	--	--	--	82.7
06/18/75	--	--	--	--	1.9	--	106.2
06/22/75	--	1.1	--	--	1.7[e]	--	71.7
07/01/75	--	--	--	--	7.1	--	283.2
07/19/75	.6	20.1	--	--	14.7	--	164.8
08/01/75	.9	12.5	--	20.4	7.9	7.9	66.3
08/05/75	< .1	9.1	--	7.1	6.8	3.2	16.4
08/12/75	< .1	6.5	3.1	11.1	3.7	3.4	14.2
08/20/75	u	1.1	.6	4.3	1.4	1.7	16.1
08/27/75	u	1.1	2.3	3.1	2.6	.9	15.9
09/06/75	u	.3	.6	.9	2.6	.6	9.4
09/09/75	u	.6	.6	1.4	2.6	.6	11.3
09/23/75	u	u	u	d	2.0	.1	25.2

[a] Dash indicates no record
[b] u indicates unmeasurable small flow
[c] d indicates dry
[d] s indicates snow covered
[e] Estimated

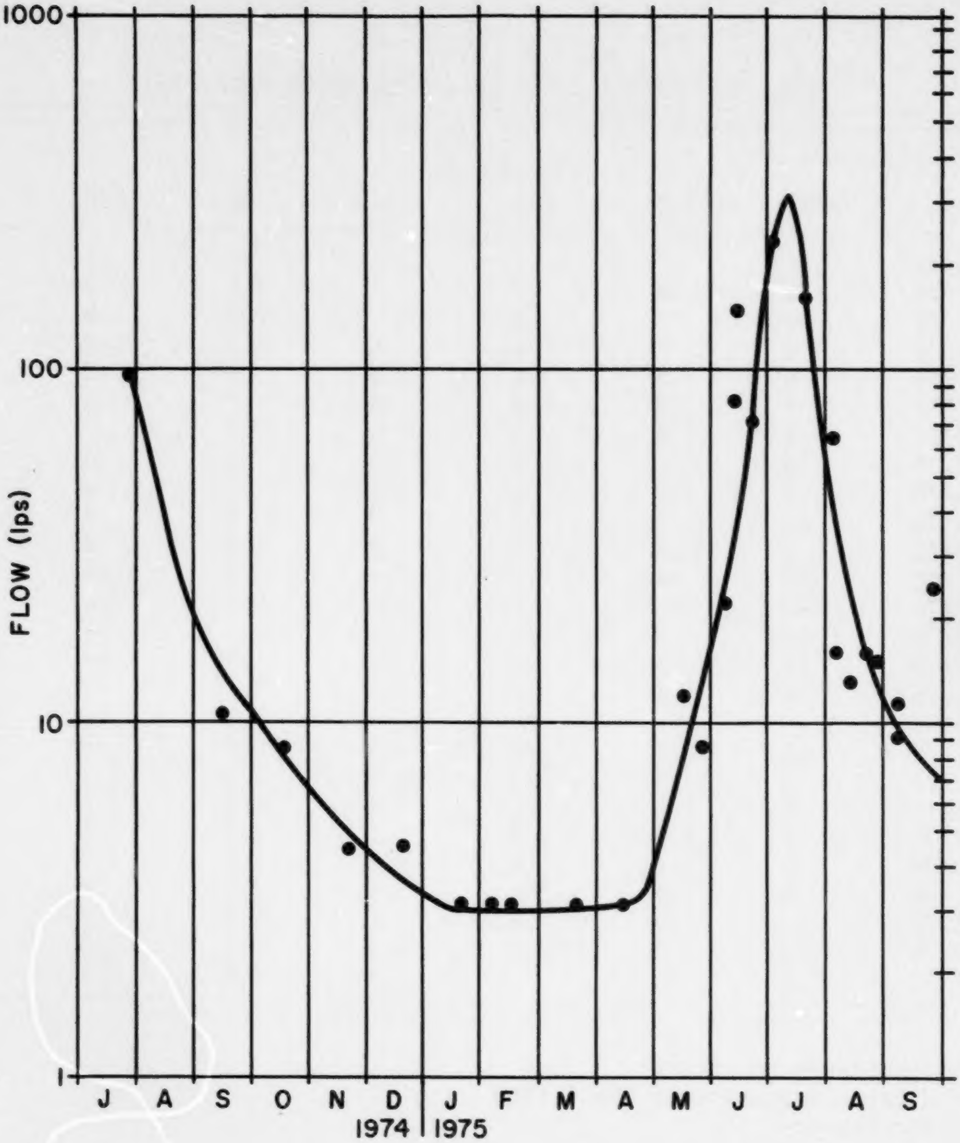


FIGURE 9 Hydrograph for Fisher Creek at site 207, Glengary mine area.

TABLE 5. PRECIPITATION DATA FROM SOIL CONSERVATION SERVICE STORAGE PRECIPITATION GAUGE, FISHER CREEK DRAINAGE BASIN.

	Water Year								
Month	1967	1968	1969	1970	1971	1972	1973	1974	1975
Oct	48.3[a]	145.3	78.7	73.7	60.7	81.8	72.1	63.8	--[b]
Nov	205.2	157.7	162.8	112.5	275.1	141.7	92.5	275.1	--
Dec	131.1	170.7	192.5	138.4	228.9	252.0	184.4	162.1	--
Jan	418.1	180.3	363.7	354.8	390.9	408.2	102.6	292.6	283.7
Feb	186.2	150.9	82.3	118.9	174.8	254.3	84.3	141.7	195.6
Mar	245.6	101.9	61.0	164.9	248.9	190.3	98.6	450.6	--
Apr	108.7	67.6	83.8	165.1	98.0	247.9	194.1	188.7	--
May	193.0	96.5	83.8	79.5	45.5	90.0	120.7	158.2	--
June	150.0	149.6	165.1	92.5	40.4	85.3	100.6	121.7	--
July	61.0	50.8	76.2	59.4	74.2	59.2[c]	36.8[c]	68.1	--
Aug	17.8	139.7	20.3	18.8	78.7	70.6[c]	36.1[c]	65.5[c]	--
Sept	40.6	111.3	53.9	132.1	102.4	152.2[c]	103.1[c]	28.5[c]	--
TOTAL	1805.6	1522.3	1424.1	1510.6	1818.5	2033.5	1225.9	2016.6	--

[a] Data is in mm. The gauge is at 2,698 m elevation

[b] Dash indicates no data recorded

[c] Estimates monthly totals from Mystic Lake and Cooke City data

Water Chemistry

Data Base. A compilation of partial chemical analyses for water samples from the mine areas is shown in Appendix E. Those components with few samples are not listed. During 1973, some of the samples collected were run for only the expected heavy metals. Complete standard analyses for Ca, Mg, Na, K, Fe, Mn, Al, SiO_2, HCO_3, SO_4, Cl, F, and NO_3 were run on samples collected from 1974 on, except for samples collected the first and second weeks in June 1975, when only total recoverable iron samples were collected. All of these data are available from the Montana DNRC.

Snow samples were collected in mid-May to be used to estimate precipitation loads of heavy metals and major elements and snowpack water available for runoff. The chemical analyses, listed in Appendix F, indicate a significant fallout source of chloride and sulfate.

Percent Iron Reaching the Stream. In order to calculate the percentage of iron reaching the surface waters three assumptions were necessary: (1) that sulfide minerals were the sole source of sulfur other than the 11.3 mg/l average value for sulfate in the snow, (2) that pyrite was the predominant sulfide mineral, and (3) that sulfur (as sulfate) remained dissolved in the water. Using the data for September 16, 1974, a value of 49.5 percent was obtained for the amount of dissolved iron, released by weathering, which actually reaches the surface waters. The calculations involved are presented in Appendix D, page 138. Figure 10, page 37, is a plot for determining the percentage iron released to the sampling point by the weathering of pyrite. The data points shown on the figure are for samples collected at the mine adit (site 205) along Fisher Creek. Both dissolved and total recoverable iron are shown. It is noted that for the average sample only about one-half of the iron released by pyrite dissolution weathering reaches the mine portal. The three samples for which the total recoverable iron transported is greater than or equal to 75 percent of the released iron (calculated) were all collected on the rising limb of the adit discharge. This suggests that some of the finer precipitate in the tunnel is transported out of the workings each year.

The Mixing of Dissimilar Stream Waters

Mixing of surface waters occurs within or adjacent to the site areas. The mixing of mining-affected surface waters with essentially unaffected waters from adjacent tributaries may have differing effects depending upon the composition of the waters. The most common result of such mixing is the precipitation of ferric hydroxide and other heavy metals downstream from the intersection of the two streams. This reaction is believed to result from the catalytic effect of the hydroxyl ion concentration (Stumm and Morgan, 1970, -- 534-540), which is generally 1,000 times larger in the unaffected tributary.

An example from Fisher Creek based on data collected on September 16, 1974, will suffice to show the effectiveness of mixing reactions upon iron concentrations. Flow from the adit (site 205) was 3.4 lps, and the

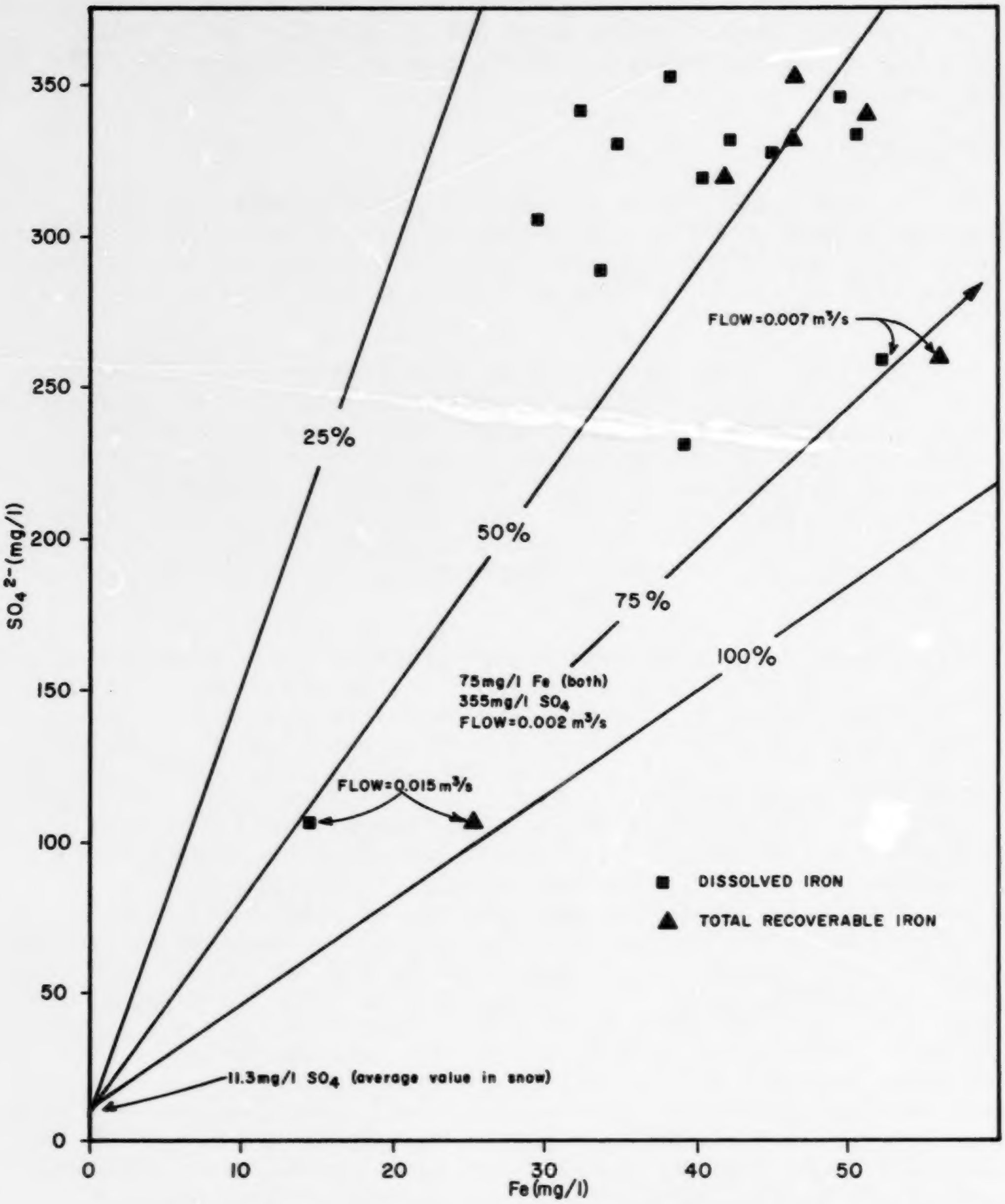


FIGURE 10 Iron versus sulfate plot for water samples collected at the lower adit (site 205), Glengary mine area. The heavy lines indicate the percentage of the iron, liberated by pyrite oxidation, which reached the sampling site.

dissolved iron concentration was 45.3 mg/l. Downstream 365 m, at site 207, the flow had increased to 12.2 lps, and the dissolved iron content had decreased to 4.0 mg/l. This represents a minimum decrease of 68 percent of the dissolved iron content in the water and is equivalent to an annual precipitation of approximately 3.3 metric tons of iron within the 365 m stream reach.

Discussion

The two mine areas will be discussed together to emphasize their differences in water quality. The major factors causing these differences are believed to be, in order of importance; (1) mining methods employed, (2) topographic settings, (3) type and extent of mineralization, and (4) geologic association.

Both Daisy and Fisher Creeks may be characterized as containing acid, calcium sulfate waters with abnormally high conductivities, dissolved solids, aluminum, iron, manganese, and trace metal concentrations (Appendix E). They both respond in a similar fashion to the snowmelt "dilution effect" upon water quality as shown in Figure 11, page 39, for samples collected at the respective gauging stations. Both creeks have very little variation in specific conductance in their low-flow regime (< 10. lps), which suggests a fairly constant ratio of mine drainage contribution to the base flow of the stream during the low-flow period.

The major difference between the two drainages is the magnitude of their metal loads, especially iron and aluminum. At the weir location on Daisy Creek (site 109), dissolved iron ranges from 5.4 to 34.6 mg/l, total recoverable iron ranges from 23.2 to 99.0 mg/l, and dissolved aluminum ranges from 9.32 to 41.3 mg/l; while at the weir on Fisher Creek (site 207), dissolved iron ranges from 1.4 to 6.4 mg/l, total recoverable iron ranges from 1.9 to 4.5 mg/l, and dissolved aluminum ranges from 1.0 to 3.65 mg/l. These differences are roughly fivefold for dissolved iron and tenfold for total recoverable iron and dissolved aluminum. Dissolved iron and aluminum concentrations were found to be independent of pH at the Fisher Creek weir site, and to have a very slight negative correlation (increasing metal values with increasing pH) at the Daisy Creek weir site. Computer calculations using a program designed to calculate solution composition and compare it with mineral solubilities (Truesdell and Jones, 1973), for samples collected on August 5, 1975, did not determine the waters to be saturated with respect to any aluminum-bearing minerals, but supersaturation with respect to ferric hydroxide, ferric oxyhydroxide, and ferric oxide occurred at both weir sites. Lepidocrocite and jarosite were not included in the computer calculations; manual computations show that the waters are supersaturated with respect to both of these phases.

Although these observations can be explained in part by equilibrium chemistry, flow paths and reaction kinetics must also be considered with these systems. Sulfate ions form ion complexes with various metal ions in aqueous solutions. In dilute waters the effect of these complexes is negligible, but, as one or both of their concentrations rise, the percentage of less abundant species found as a complexed species increases markedly.

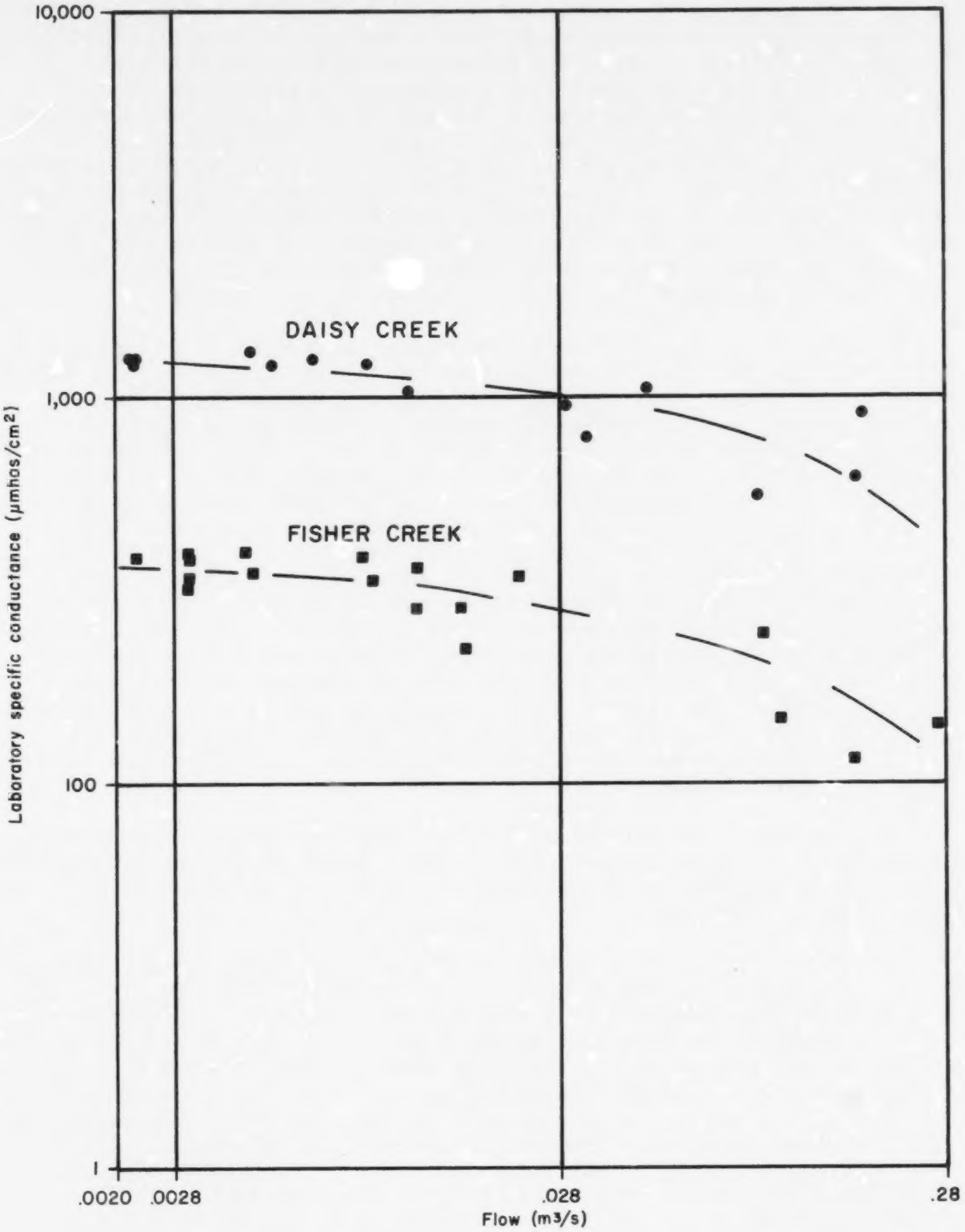


FIGURE 11 Flow versus specific conductance for waters collected at sites 109 and 207.

As an example, at sites 207, 205, 109, and 103 the percentage of aluminum tied up in aluminum sulfate complexes is 26.7, 49.6, 52.4, and 66.6 percent, respectively. Thus the weathering of pyrite produces acid, which attacks the aluminous minerals and provides sulfate, which helps to keep the aluminum in solution. The results of the computer calculations are not surprising, as the difference between the analytically determined dissolved and total recoverable aluminum was small, usually falling within the analytical limits of the equipment, and one form was not consistently higher or lower than the other. Also, the aluminum determinations on raw and raw filtered samples showed the same results, implying that aluminum was stable (undersaturated) in the waters sampled. These facts do not explain the reason for the order of magnitude difference in the aluminum values noted between the two mine areas.

The solution to this problem can be easily understood if the water samples collected at the collapsed adit on the McLaren property (site 108) are thought of as representative of an oxygen-deficient system. These water samples may be characterized as having a neutral pH, moderate sulfate content, and low (relative to the other sites) metal concentrations. They must represent a situation where neutralization of the acid formed by pyrite oxidation [equation (3), Appendix D] has kept pace with acid production. Neutralization has probably been achieved predominantly by the dissolution of limestone [equation (8), Appendix D], as the calcium content represents 75 to 84 percent of the positive ionic charge (cation milliequivalents). Calcite dissolution is one of the more rapid mineral reactions, geologically speaking, and it is logical to assume that the rate-limiting factor controlling the water composition is the availability of oxygen. If the water samples from this site and the proposed limiting factor are taken as one extreme and the oxygenated waters recharging through small ponds, as typified by samples from the "wet well" (site 110), are taken as the other extreme (see Appendix E), it can be seen that the latter must be the dominant type of reaction occurring at the McLaren mine area.

The iron data is consistent with this interpretation also. Rather than repeat what is in the literature, the reader is referred to Langmuir (1971), Langmuir and Whittemore (1971), Whittemore (1973), and Whittemore and Langmuir (1972, 1974, 1975).

Several factors interact to control the quality of AMD in this type of terrain. The type of mining is believed to be most crucial. Open-pit mining destroys the thin soil of subalpine areas, but more importantly it vastly increases the amount of unweathered sulfide mineral surface in contact with the atmosphere and shallow groundwater systems. This increases the rate of sulfide weathering drastically. The topography of the mine area is important to the groundwater flow system. Steep topography results in steep groundwater gradients, thereby bringing dilute, unsaturated, and oxygenated water into contact with the sulfide minerals, so that the total flux of metals out of the mineralized area may be surprisingly large.

The lower metal concentrations in the Fisher Creek drainage may be attributed to the following factors: (1) the area and depth of disturbance is smaller, (2) the amount of ore minerals seems to be less, and (3) flow through the mineralized area is predominantly open-channel flow rather than groundwater flow. Thus, the velocities are considerably greater, and the chemical reactions do not have time to proceed as far before the water has passed through the major mineralized zone.

One additional feature should be noted before finishing the discussion of the mine areas. The total suspended (or total filterable) sediment in a subalpine stream usually increases as a function of flow. Figure 12, page 42, a plot of flow versus suspended solids, shows two interesting features. First, Daisy Creek (circles) seems to be almost unaffected by stream stage, averaging roughly 62 mg/l of suspended solids for flows ranging from 5.4 to 173 lps. Second, the Fisher Creek data (triangles) may be interpreted by either of the curves as showing a minimum suspended solids content for flows of about 28 lps, with suspended solids increasing with both higher and lower stream discharges. The sparsity of available data and the absence of winter data (flows <3.7 lps) limit the significance of the figure, but if these trends are valid, the following interpretations should be of significance:

1. At the McLaren mine area, the consistency of the suspended solids content suggests that the surficial sediment load approximately balances the runoff dilution effect upon filterable precipitates.

2. At the Glengary mine area, the high flow characteristics are typical of unaffected watersheds, but the precipitation of iron from the adit discharge reverses this trend at low flows when the adit discharge becomes volumetrically more important.

Summary of Metal Loads at McLaren Mine Site. An analysis of the annual flow and total metal load will help to summarize the sources and extent of pollution. In deriving the loads at various sites at the two mine locations, we can more easily identify the pollutant sources and, if reclamation work is completed, determine the reduction in pollutant load.

To determine the loads, water year 1975 (October 1, 1974 to September 30, 1975) was used to compare the pollutant loads at each site. Streamflow and water quality data were gathered periodically at sites at each mine area. The average streamflow and water quality data for the period between each sample were determined by averaging the data obtained from the samples at the beginning and end of each period. The metal load was calculated by multiplying the average flow by the duration of the time period, and multiplying the resultant number by the laboratory determination of the metal concentrations. For those sites that did not have numerous streamflow and water quality data available, the time interval for the representative flow rate and sample was extended to include that portion of the year when the sample would represent a similar flow and water quality regime. For example, if one flow rate and water quality sample were collected during spring runoff, it was assumed that this flow and water quality were characteristic of the entire spring runoff. Spring runoff and low flow periods were determined from sites 109 and 208 which had numerous water quality samples and continuous flow measurements.

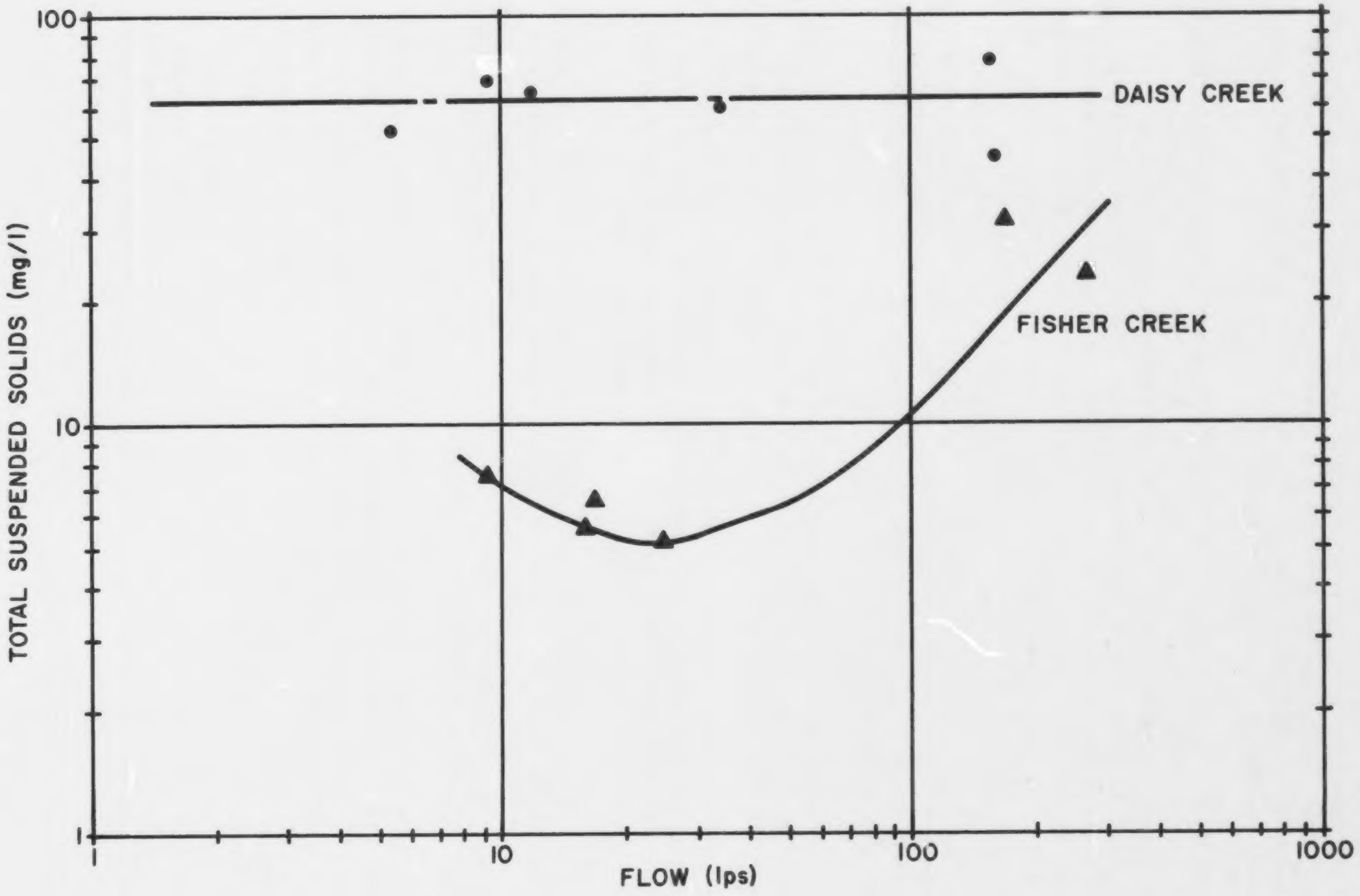


FIGURE 12 Flow versus total suspended solids for Daisy and Fisher Creeks at their gauging stations.

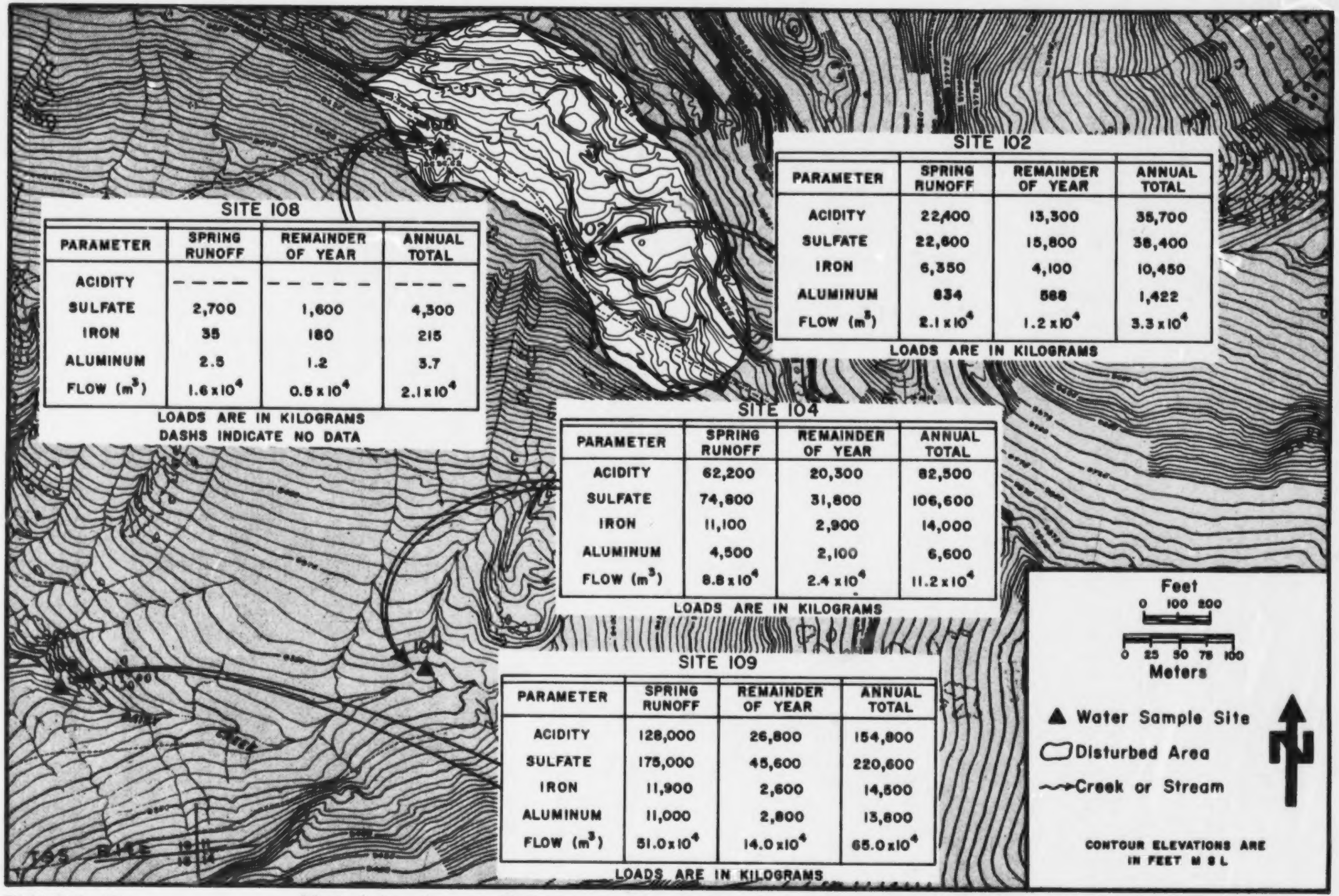
Figure 13, page 44, shows the metal loads for the McLaren mine area at sites 102, 104, 108, and 109 for the spring runoff (May 15, 1975 to August 5, 1975), the remainder of water year 1975 (October 1, 1974 to May 15, 1975 and August 5, 1975 to September 30, 1975), and the total load for water year 1975.

Based upon the discharge and water quality data collected at site 109 for the October 1974 to September 1975 period, the annual contribution of the McLaren mine site is as follows: acidity, 154,800 kg; sulfate, 220,600 kg; iron, 14,500 kg; and aluminum, 13,800 kg. Although the amount of data available was less, copper loads have been estimated at 3,300 kg per year and zinc at one-tenth that value. These figures are probably on the conservative side since flows during most of the snowmelt periods and summer storm events were not measured. The impact of a summer storm can be seen by the samples collected on July 30, 1975 at site 103 (Table 6, page 45). The concentration of most constituents increased during the storm with the greatest increase occurring in iron, sulfate, and suspended solids. Thus, the 148 percent increase in discharge did not result in dilution of the pollutants, but caused a flush off of reaction products and suspended matter.

Approximately 80 percent of the pollution load was discharged during the snowmelt period (May to July) when the major contribution to flow was surface runoff. On July 30, 1975, a survey was made of the mine site to determine the major sources of pollutants. At that time there were only a few small patches of snow remaining near the highwall. As seen in Figure 14, page 46, a small tributary measured at site 104 was receiving the majority of its flow from water that had infiltrated into the mine waste and was resurfacing down gradient. Over half the discharge at site 103 can be contributed to underflow. As this water passed through the mine waste, significant increases in all parameters resulted. The water that percolated further to seeps measured at sites 117, 118, and 119 picked up even higher concentrations of heavy metals. The springs in the vicinity of site 104 are somewhat of a puzzle. They appear to be separated from the mine area by a ridge and have a higher aluminum concentration. Their source is not clear. The tributary at site 107 obtains most of its flow from the seepage and pond at site 106. The groundwater appears to surface at this point. The water quality at site 107 is better than at site 104, probably reflecting less impact of the disturbed mine area which primarily drains toward site 104.

Summary of Metal Loads at Glengary Mine Site. Figure 15, page 47, shows the metal loads for the Glengary mine site at sites 202, 205, and 207 for the spring runoff, the remainder of water year 1975, and the total load for water year 1975. Site 205 reflects the metal load from the mine adit, and site 207 shows the total load from the disturbed mine areas as well as the load from the mine adit.

Based upon the discharge and water quality data collected over the September 1974 to September 1975 period at site 207 on Fisher Creek (Figure 15, page 47), the annual contribution of pollutants was as follows: acidity, 28,000 kg; sulfate, 54,400 kg; iron, 2,180 kg; and aluminum,


Feet
0 100 200
0 25 50 75 100
Meters
▲ Water Sample Site
Disturbed Area
Creek or Stream
CONTOUR ELEVATIONS ARE IN FEET M S L
102
104
108
109

SITE 108

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
ACIDITY	----	------	----
SULFATE	2,700	1,600	4,300
IRON	35	180	215
ALUMINUM	2.5	1.2	3.7
FLOW (m^3)	1.6×10^4	0.5×10^4	2.1×10^4

LOADS ARE IN KILOGRAMS
DASHS INDICATE NO DATA

SITE 102

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
ACIDITY	22,400	13,300	35,700
SULFATE	22,600	15,800	38,400
IRON	6,350	4,100	10,450
ALUMINUM	834	588	1,422
FLOW (m^3)	2.1×10^4	1.2×10^4	3.3×10^4

LOADS ARE IN KILOGRAMS

SITE 104

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
ACIDITY	62,200	20,300	82,500
SULFATE	74,800	31,800	106,600
IRON	11,100	2,900	14,000
ALUMINUM	4,500	2,100	6,600
FLOW (m^3)	8.8×10^4	2.4×10^4	11.2×10^4

LOADS ARE IN KILOGRAMS

SITE 109

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
ACIDITY	128,000	26,800	154,800
SULFATE	175,000	45,600	220,600
IRON	11,900	2,600	14,500
ALUMINUM	11,000	2,800	13,800
FLOW (m^3)	51.0×10^4	14.0×10^4	65.0×10^4

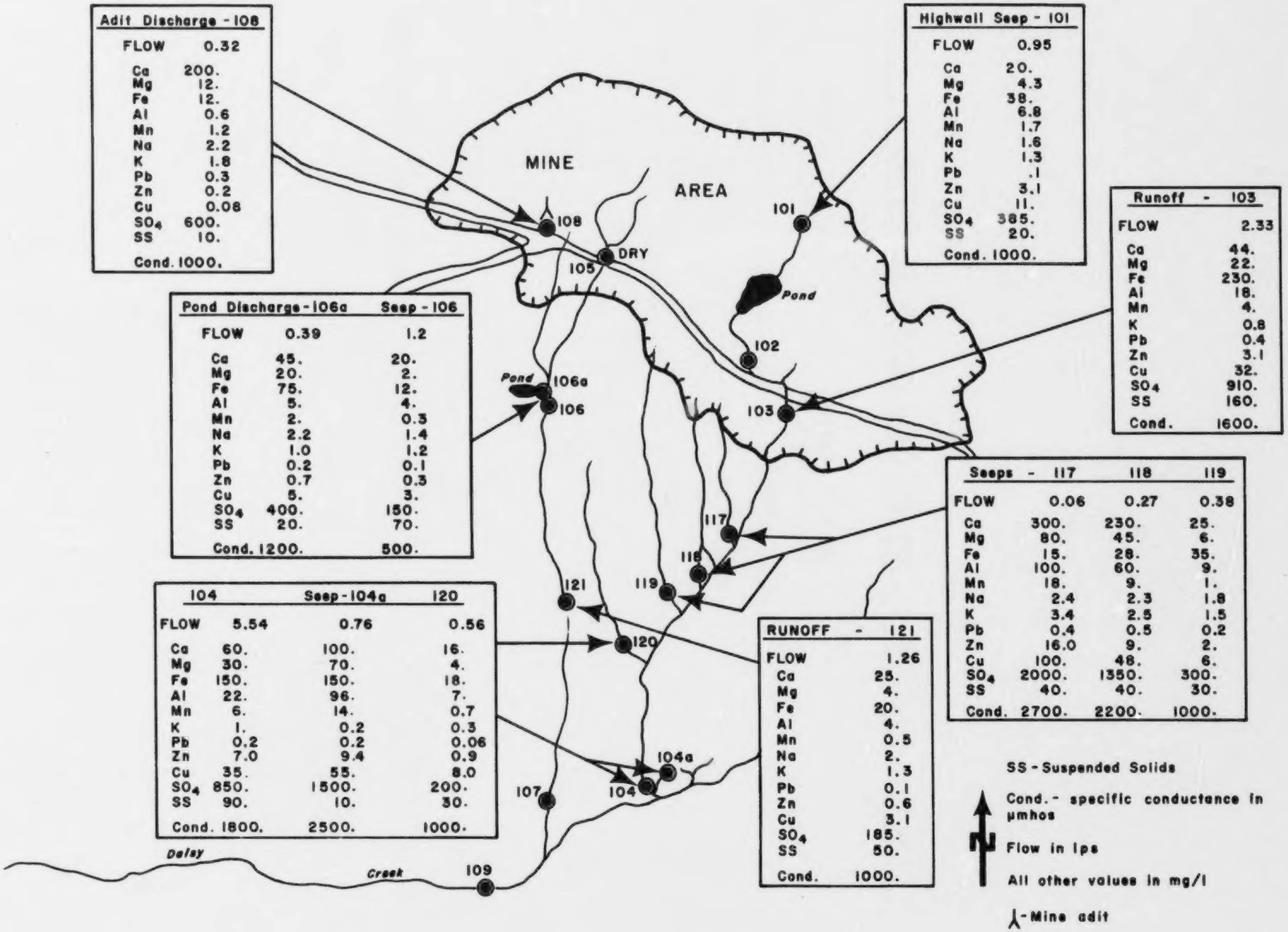
LOADS ARE IN KILOGRAMS

FIGURE 13 Metal loads at McLaren mine site for water year 1975.

TABLE 6. IMPACT OF A STORM ON RUNOFF QUALITY AT SITE 103

	Before storm[a] concentration mg/l	During storm[b] concentration mg/l
Ca	44	100
Mg	22	18
Fe, total	230	720
Al	18	18
Mn	4	4
Na	1	2
Cd	.04	.02
K	.8	2
Pb	.4	1
Zn	8	5
Cu	32	25
SO_4	910	1,800
Suspended solids	160	7,710

[a] Flow rate = 2.33 lps
[b] Flow rate = 5.8 lps


MINE
AREA
Pond
Pond
DRY
101
102
103
104
104a
105
106
106a
107
108
109
117
118
119
120
121
Daisy
Creek
SS - Suspended Solids
Cond. - specific conductance in μmhos
Flow in lps
All other values in mg/l
⅄-Mine adit

Adit Discharge - 108	
FLOW	0.32
Ca	200.
Mg	12.
Fe	12.
Al	0.6
Mn	1.2
Na	2.2
K	1.8
Pb	0.3
Zn	0.2
Cu	0.08
SO_4	600.
SS	10.
Cond.	1000.

Highwall Seep - 101	
FLOW	0.95
Ca	20.
Mg	4.3
Fe	38.
Al	6.8
Mn	1.7
Na	1.6
K	1.3
Pb	.1
Zn	3.1
Cu	11.
SO_4	385.
SS	20.
Cond.	1000.

Runoff - 103	
FLOW	2.33
Ca	44.
Mg	22.
Fe	230.
Al	18.
Mn	4.
K	0.8
Pb	0.4
Zn	3.1
Cu	32.
SO_4	910.
SS	160.
Cond.	1600.

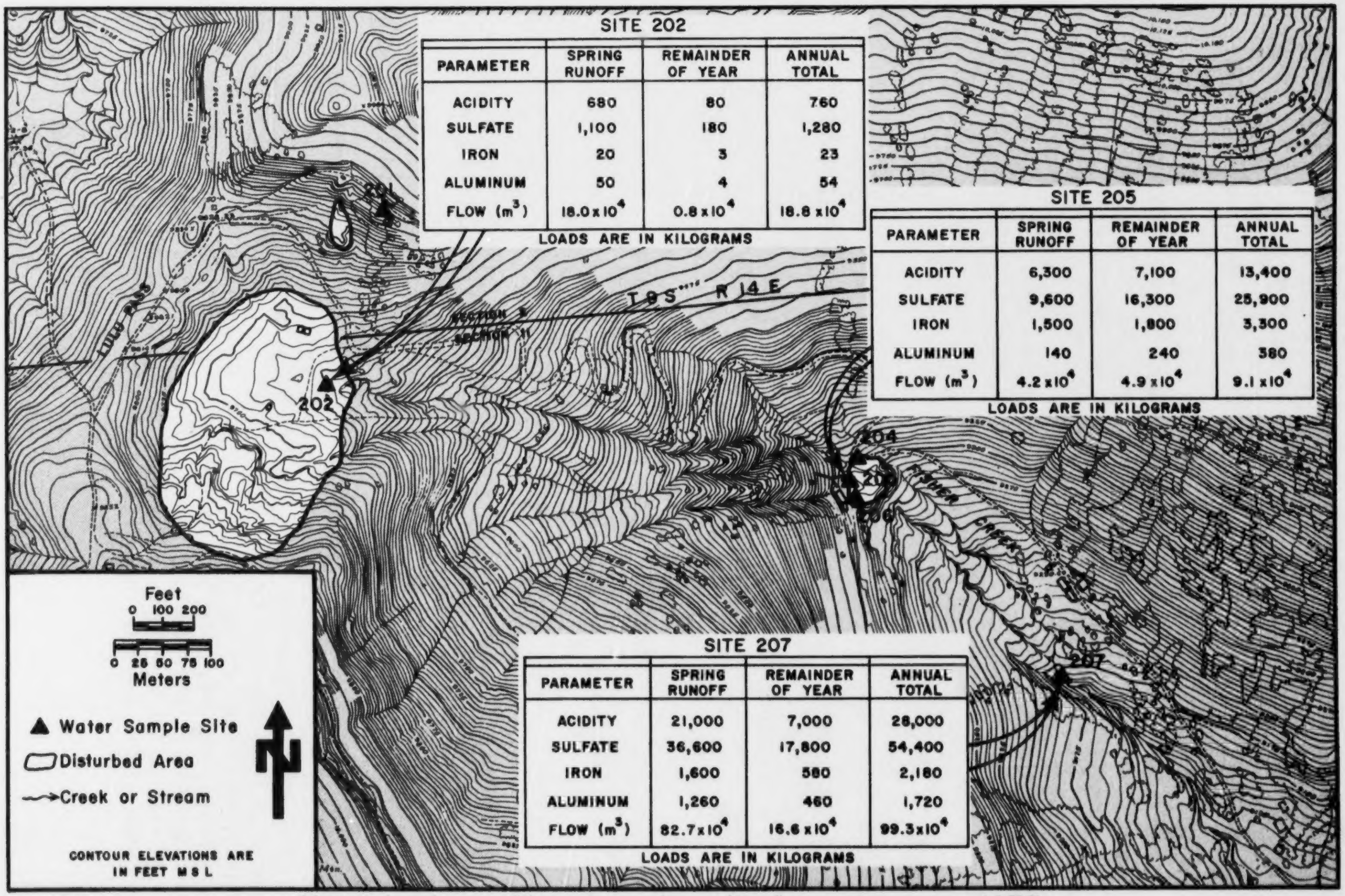
	Pond Discharge - 106a	Seep - 106
FLOW	0.39	1.2
Ca	45.	20.
Mg	20.	2.
Fe	75.	12.
Al	5.	4.
Mn	2.	0.3
Na	2.2	1.4
K	1.0	1.2
Pb	0.2	0.1
Zn	0.7	0.3
Cu	5.	3.
SO_4	400.	150.
SS	20.	70.
Cond.	1200.	500.

Seeps -	117	118	119
FLOW	0.06	0.27	0.38
Ca	300.	230.	25.
Mg	80.	45.	6.
Fe	15.	28.	35.
Al	100.	60.	9.
Mn	18.	9.	1.
Na	2.4	2.3	1.8
K	3.4	2.5	1.5
Pb	0.4	0.5	0.2
Zn	16.0	9.	2.
Cu	100.	48.	6.
SO_4	2000.	1350.	300.
SS	40.	40.	30.
Cond.	2700.	2200.	1000.

	104	Seep - 104a	120
FLOW	5.54	0.76	0.56
Ca	60.	100.	16.
Mg	30.	70.	4.
Fe	150.	150.	18.
Al	22.	96.	7.
Mn	6.	14.	0.7
K	1.	0.2	0.3
Pb	0.2	0.2	0.06
Zn	7.0	9.4	0.9
Cu	35.	55.	8.0
SO_4	850.	1500.	200.
SS	90.	10.	30.
Cond.	1800.	2500.	1000.

RUNOFF - 121	
FLOW	1.26
Ca	25.
Mg	4.
Fe	20.
Al	4.
Mn	0.5
Na	2.
K	1.3
Pb	0.1
Zn	0.6
Cu	3.1
SO_4	185.
SS	50.
Cond.	1000.

FIGURE 14 Water quality at McLaren mine site (July 30,1975).


201
202
204
207
T 9 S
R 14 E
SECTION 3
SECTION 11
FISHER CREEK
LULU PASS
Feet
0 100 200
0 25 50 75 100
Meters
▲ Water Sample Site
Disturbed Area
Creek or Stream
N
CONTOUR ELEVATIONS ARE IN FEET M S L

SITE 202

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
ACIDITY	680	80	760
SULFATE	1,100	180	1,280
IRON	20	3	23
ALUMINUM	50	4	54
FLOW (m^3)	18.0×10^4	0.8×10^4	18.8×10^4

LOADS ARE IN KILOGRAMS

SITE 205

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
ACIDITY	6,300	7,100	13,400
SULFATE	9,600	16,300	25,900
IRON	1,500	1,800	3,300
ALUMINUM	140	240	380
FLOW (m^3)	4.2×10^4	4.9×10^4	9.1×10^4

LOADS ARE IN KILOGRAMS

SITE 207

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
ACIDITY	21,000	7,000	28,000
SULFATE	36,600	17,800	54,400
IRON	1,600	580	2,180
ALUMINUM	1,260	460	1,720
FLOW (m^3)	82.7×10^4	16.6×10^4	99.3×10^4

LOADS ARE IN KILOGRAMS

FIGURE 15 Metal loads at Glengary mine site for water year 1975.

1,720 kg. Based upon limited data, the copper and zinc loads have been estimated as 580 kg, and 200 kg, respectively. These values are probably on the low side because of the difficulty in measuring accurate flows due to water movement through the gravels underlying the stream channel, and because of lack of data during parts of the snowmelt and summer storm periods.

Approximately 75 percent of the pollution load was discharged during the snowmelt period, May to July. During low flow period, the adit discharge measured at site 205 produced over 80 percent of the pollutants found at site 207 on Fisher Creek (Figure 15, page 47). Besides the discharge from the adit (site 205), pollutants were discharged from the Scott Bonnet Mine adit (site 201) and were picked up by the overflow across mine waste dumps. This pickup can be noted by comparing the water quality at sites 202 and 204.

Mill Area

Introduction

The mill processed ore from the McLaren mine and was located between U.S. 212 and Soda Butte Creek (Figure 2, page 11). The tailings pond begins about 120 m southwest of the old mill site, and is roughly elliptical, having axial dimensions of about 260 and 150 m. The tailings pond is over the old Soda Butte Creek stream channel; the present stream course is the result of diverting the creek around the north side of the tailings pile (Photo 4, page 49). When the Bear Creek Mining Company purchased the McLaren mine property, the mill site came with the mine in a "package" transaction. Bear Creek leveled the tailings material and covered it with roughly 0.5 to 1.0 m of alluvial sand and gravel in the 1960's.

Geology

The mill area is underlain by moraine deposits of Pleistocene age (Elliott, 1973) covered with a thin veneer of recent stream deposits. Bedrock consists of coarse-grained granite and fine-grained diorite. The diorite is believed to be a small dike, of Tertiary age, which intruded the granite. The diorite was encountered in drill hole number 24B (Figure 16, page 50 and Appendix G), which penetrated the thickest section of gravel. The 14.5 m of gravel below the tailings and above bedrock may be related to the lesser resistance of the nongranitic igneous rocks to chemical weathering (Holmes, 1960, pp. 393-400), or this hole may be located closer to the part of the valley that was deepest at the time when glacial aggradation (valley filling) began. Regardless of the origin of the gravel-filled depression, the thickness of the gravel at this location places serious engineering constraints upon any attempts to flood the tailings pond or to dam the tailings and gravel, preventing groundwater within the tailings from passing through the gravel.

Photo 4. McLaren mill area showing Soda Butte Creek.

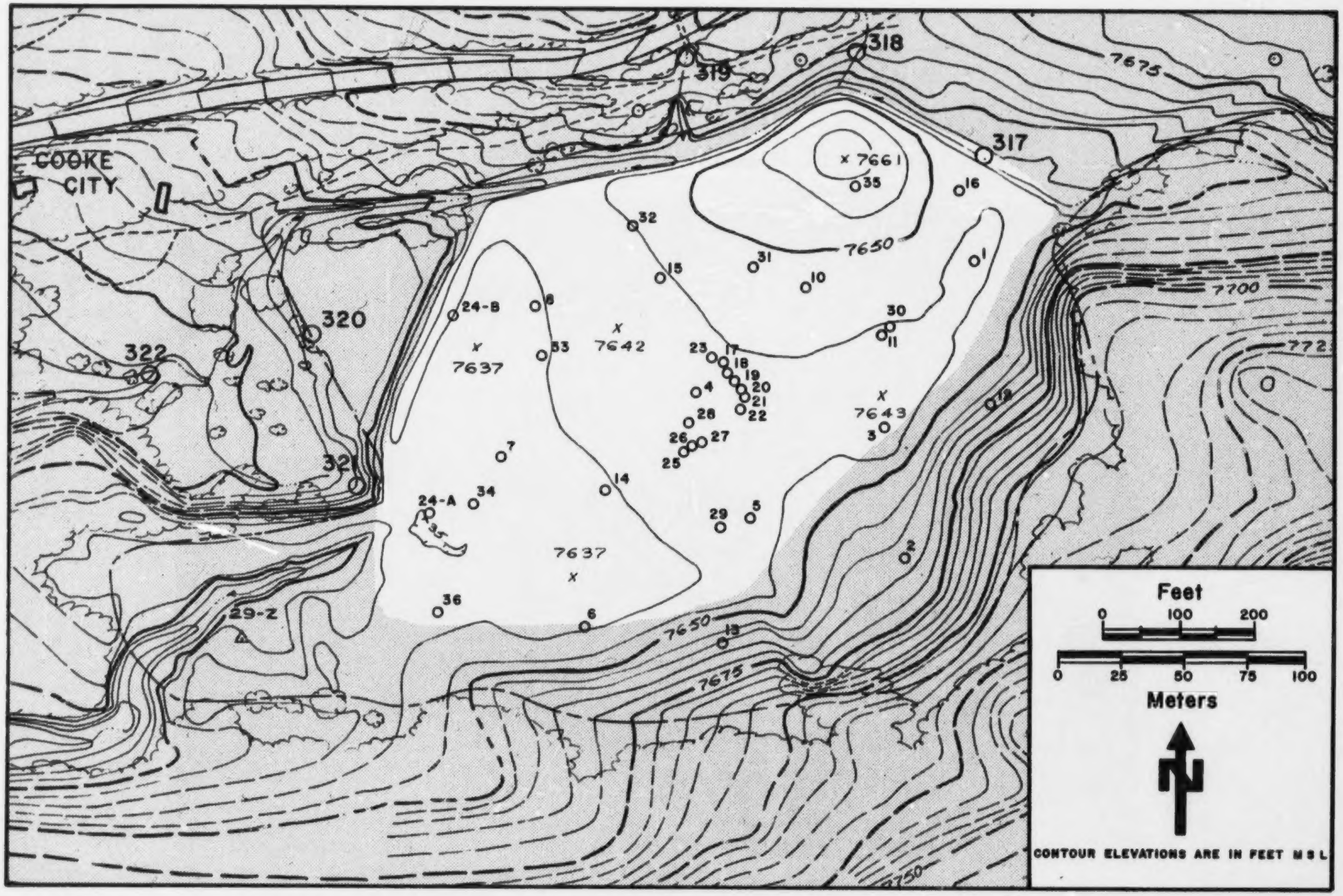

COOKE CITY
317
318
319
320
321
322
7661
7650
7643
7642
7637
7637
7675
7700
7750
29-Z
24-A
24-B
Feet
0
100
200
0
25
50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET MSL

FIGURE 16 Sample site location map of the mill tailings area. Large circles represent surface water stations; small circles represent wells. The "300" has been deleted from the well numbers.

Tailings Material

The thickness of the tailings is known to range from about 0.03 to 9.7 m. The tailings consist of phyllosilicates (clays), tectosilicates (predominantly feldspars and quartz), sulfides (mostly pyrite), iron oxides (magnetite, goethite, and ferric hydroxide), and calcium salts (gymsum and calcite). Most of the material is coarser than 325 mesh (a sieve opening of 44 microns or 0.044 mm). Chemical analyses were run on samples from nine of the holes drilled during 1975 to obtain a range for the metal values and chemical constituents that affect the smelting costs (Table 7, page 52). The Bear Creek Mining Company provided auger-location and polygonal ore-reserve maps and a tabular summary of their assay of the mine tailings. Based on the available data, the value of the tailings at current (March 1977) metal prices is: (1) gold = \$3,240,000, (2) silver = \$324,800, and (3) copper = \$1,182,400, for a total metal value in the tailings of 4.747 million dollars.

Examination of the auger cuttings and split-spoon cores indicated two significant zones of sulfide oxidation within the tailings. An upper zone of oxidation showed in all holes as red iron stain. Additional stringers of oxidized material, seemingly associated with sandy layers, were noted to a depth of 3 m. A second zone of oxidation, at the base of the tailings, was erratic. It consisted of ferric iron cementing material which, with some of the fines from the tailings, had filled the open space in the underlying sand and gravel. The cementing iron was principally goethite and one or more x-ray amorphous phases. Because goethite [$FeO(OH)$] commonly forms by the dehydration of ferric hydroxide [$Fe(OH)_3$], ferric hydroxide is believed to be the predominant x-ray amorphous phase. Thermodynamic calculations suggest that before the tailings waters become saturated with respect to ferric hydroxide, jarosite [$KFe_3(SO_4)_2(OH)_6$] saturation is reached.

Hydrology

Introduction. The tailings pond has been studied for two years, but somewhat better water level data were obtained during 1976. The tailings pond is an abnormal phenomenon, being a lenticular wedge of fine-grained sediment artifically emplaced within a stream channel and stabilized by man. The diversion of the creek around the tailings prevented the backing up of stream water, although the tailings do create a barrier that retards groundwater moving down the hill slope south of the pond from reaching the creek. The effect of the barrier is particularly visible near well 6 (Figure 16, page 50), as a seep breaks out where the tailings abut the hillside. Surface water flow from this seep through the spillway continues until fall, suggesting that the difference in transmissivity between the natural surficial materials and the tailings materials is appreciable and has significantly altered the hydrologic regime. Waters that enter the tailings, react with the sulfide tailings minerals, and pass through the tailings, return as mineralized springs, seeps, and groundwater, and degrade Soda Butte Creek below the tailings pond. Thus, the study of groundwater movement within the tailings provides important information used in evaluating possible rehabilitation measures.

TABLE 7. CHEMICAL ANALYSES OF MONTANA BUREAU OF MINES AND GEOLOGY DRILL HOLES, McLAREN MILL SITE

Drill hole no.	mg/kg Au	Ag	Weight percent Cu	Pb	Zn	SiO_2	S	Fe	Al_2O_3
22	1.40	5.02	0.349	0.150	0.100	28.22	14.14	26.96	21.84
23	2.79	4.46	0.336	0.200	0.075	33.20	11.07	22.82	27.54
25	1.95	39.62	0.246	0.175	0.012	29.36	11.24	24.60	20.90
28	2.51	7.25	0.362	0.125	0.075	26.12	14.56	27.94	20.42
29	3.35	6.70	0.284	0.100	0.100	28.22	13.49	25.19	20.01
30	7.81	8.93	0.297	0.150	0.025	28.42	14.32	27.35	20.45
31	1.95	1.40	0.181	0.075	0.025	34.14	3.38	22.82	20.24
33	0.42	6.70	0.336	0.150	0.025	28.46	11.57	25.19	20.31
34	5.02	9.49	0.427	0.125	0.037	29.46	12.91	24.50	22.00
Average	3.01	9.96	.313	.139	.053	29.51	11.85	25.26	21.63

Surface Water Investigations. Six surface water stations, numbered 317 through 322 (Figure 16, page 50) constitute the standard data collection network. The data are presented in Table 8, page 54. Perennial flow exists at sites 317 (Photo 5, page 55), 321, and 322. The stream at site 318 is ephemeral, flowing only during the snowmelt runoff period. Miller Creek (319) should be a perennial stream, but the municipal water supply for Cooke City is taken from this stream, causing it to become dry in the fall of 1974. At least a part of the flow of Miller Creek was diverted during peak runoff in the summer of 1975 by erosion of the stream channel and the formation of an alternate channel. The alternate channel routed water around the study area and delivered it to Soda Butte Creek below site 322. Both sites 318 and 319 were dry by September 9, 1975. Site 320 is on the outflow of a pond formed by the coalescence of several seeps along the foot of the tailings dam. Measurable flow continued at this site beyond September 22, 1975, but ceased by October 20. Site 321 is a spring at the toe of the tailings dam. It is located approximately where a culvert carried Soda Butte Creek underneath the tailings before the creek was diverted around the tailings.

The hydrographs for sites 317 and 322 are shown in Figures 17 and 18, pages 56 and 57 ; note that from fall through spring the upper station has a higher measurable flow than the lower station. This was attributed to increasing amounts of stream underflow, just above station 318 and particularly in the lower part of the drainage beyond the tailings dam, based upon: (1) the crossing by the creek of its old stream channel, (2) the types of vegetation noted there, and (3) the high soil moisture noted in the fall. A backhoe pit was dug just upstream of site 322 to test this hypothesis. Boulders were encountered to a depth of 2.4 m, which indicates a zone of very high transmissivity extending down to at least this depth. Conditions in the channel of Soda Butte Creek near site 318 should be similar. Hole number 35 was drilled to test for the presence of a granite knob suggested in an earlier report (Wallace et al., 1975). Instead of the hypothetical shallow granite, interbedded sandy gravel and tailings to a depth of 5.1 m and boulders from 5.1 to 6.7 m were drilled. These findings verify the highly transmissive conditions necessary for highly influent stream behavior and significant underflow.

Detailed streamflow measurements were conducted on June 21, 1975 (Table 9, page 59). The stream-gauging stations (Figure 19, page 58) were selected for position along the stream reach as well as for the best available channel condition. The largest stream losses were between stations one and two (178 lps) and between stations nine and ten (213 lps). Total stream loss amounted to 388 lps, approximately 52 percent of the streamflow at the bottom station. A less detailed study on October 20, 1975, showed a stream loss of 31 lps with a flow of 32 lps at station 12; the largest loss occurred between stations one and three. These data suggest that the annual water outflow from this area is roughly twice the measured annual streamflow at the lower station.

When recorder or frequent manual measurements are available to construct a stream hydrograph, the effect of rainfall and snowmelt can be evaluated and compared to the basin's groundwater base-flow component of

TABLE 8. McLAREN MILL SITE STREAMFLOW DATA (lps)

	Site number					
Date	317	318	319	320	321	322
05/03/74	--	--	--	--	--	71
05/14/74	102	--	--	--	--	138
05/21/74	103	--	--	--	--	138
05/28/74	543	--	--	--	--	703
06/10/74	628	13	173	--	8	917
06/25/74	1308	134	1133[b]	8	8	3030[b]
07/08/74	606	34	397	34	7	1088
07/24/74	245	--	170	8	5	440
08/05/74	157	--	62	4	5	228
08/20/74	110	--	9	0.8	3	111
09/06/74	65	--	--	0.8	3	52
09/18/74	61	--	--	--	2	33
10/01/74	41	--	--	--	2	26
10/14/74	53	--	--	--	2	16
11/06/74	60	--	--	--	2	15
11/18/74	30	--	--	--	2	11
12/03/74	22	--	--	--	1	13
12/16/74	17	--	--	--	2	7
01/03/75	18	--	--	--	2	7
01/13/75	13	--	--	--	2	5
01/29/75	10	--	--	--	2	4
02/05/75	10	--	--	--	2	5
02/18/75	9	--	--	--	2	4
03/05/75	9	--	--	--	2	4
03/19/75	13	--	--	--	1	4
04/01/75	8	--	--	--	2	5
04/14/75	8	--	--	--	1	7
04/30/75	7	--	--	--	1	4
05/19/75	94	--	--	--	4	75
05/27/75	46	--	--	--	4	49
06/05/75	492	32	121	--	7	664
06/06/75	853	20	371	--	7	855
06/12/75	676	11	110	--	7	868
06/17/75	920	17	352	--	8	1122
06/21/75	892	7	196	--	44[b]	751
07/01/75	1623	116	960	11	7	2832[b]
07/09/75	1076	316	VH[c]	2	8	VH
07/21/75	330	175	274	--	8	787
07/29/75	370	76	49	3	7	396
08/04/75	249	50	22	7	3	272
08/13/75	184	12	12	2	5	191
08/19/75	187	8	9	0.9	4	128
08/26/75	146	9	5	0.9	4	110
09/04/75	79	3	6	1	4	95
09/09/75	92	DRY	DRY	0.9	4	46
09/22/75	71	DRY	DRY	0.1	3	49
10/20/75	60	DRY	DRY	DRY	3	32

[a] Dash indicates no record
[b] Estimated
[c] Very high

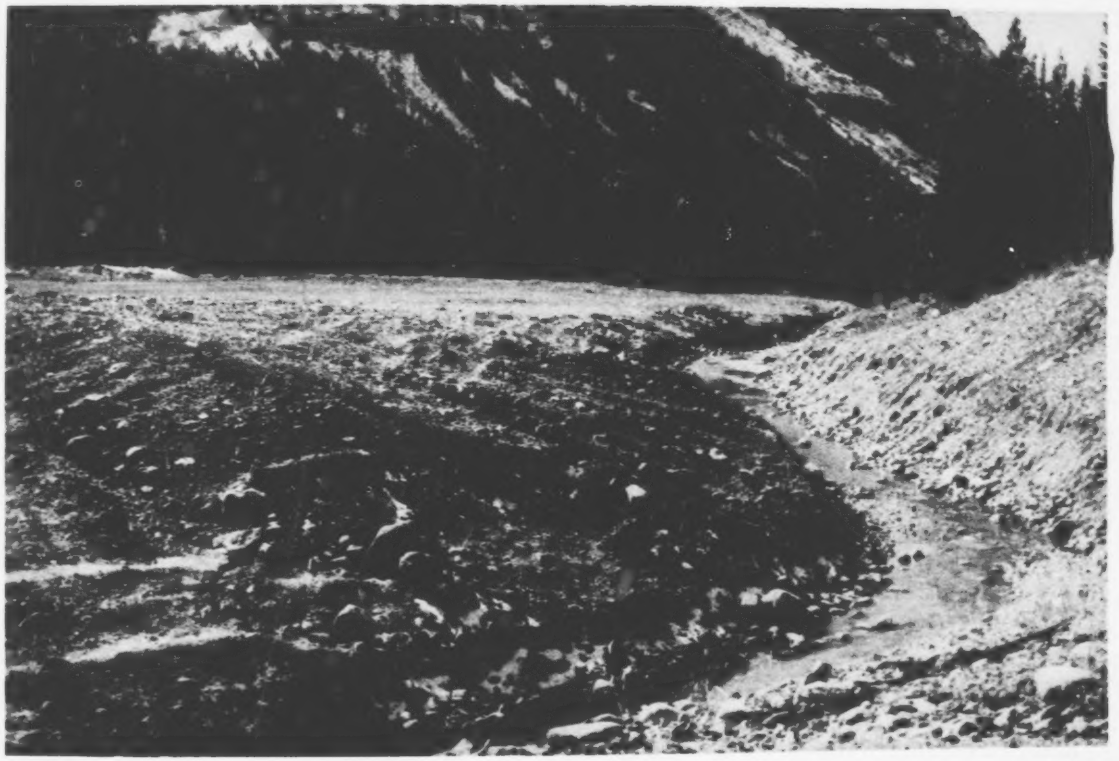


Photo 5. Soda Butte Creek near site 317.

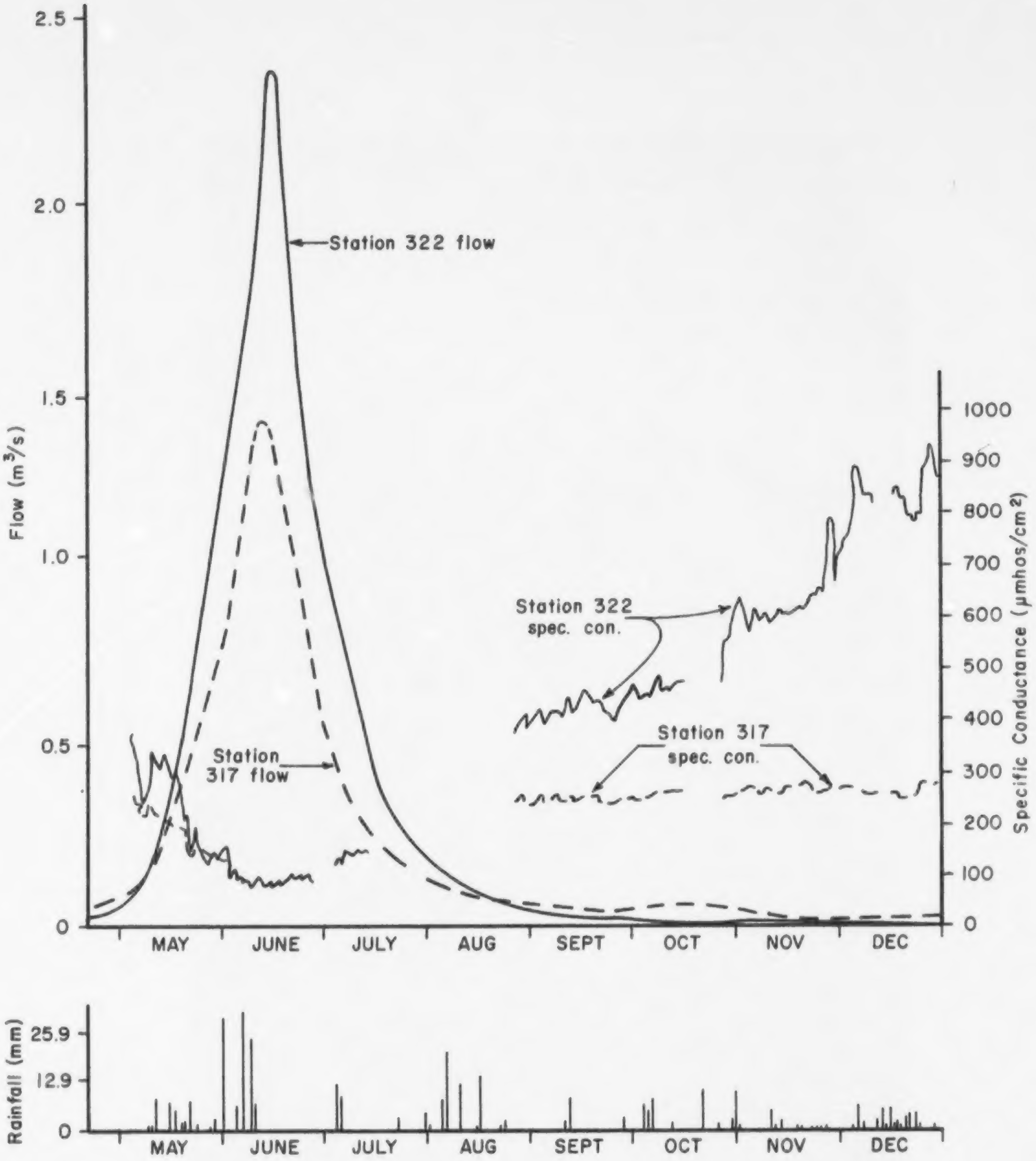


FIGURE 17 Hydrographs for Soda Butte Creek at sites 317 and 322 for 1974.

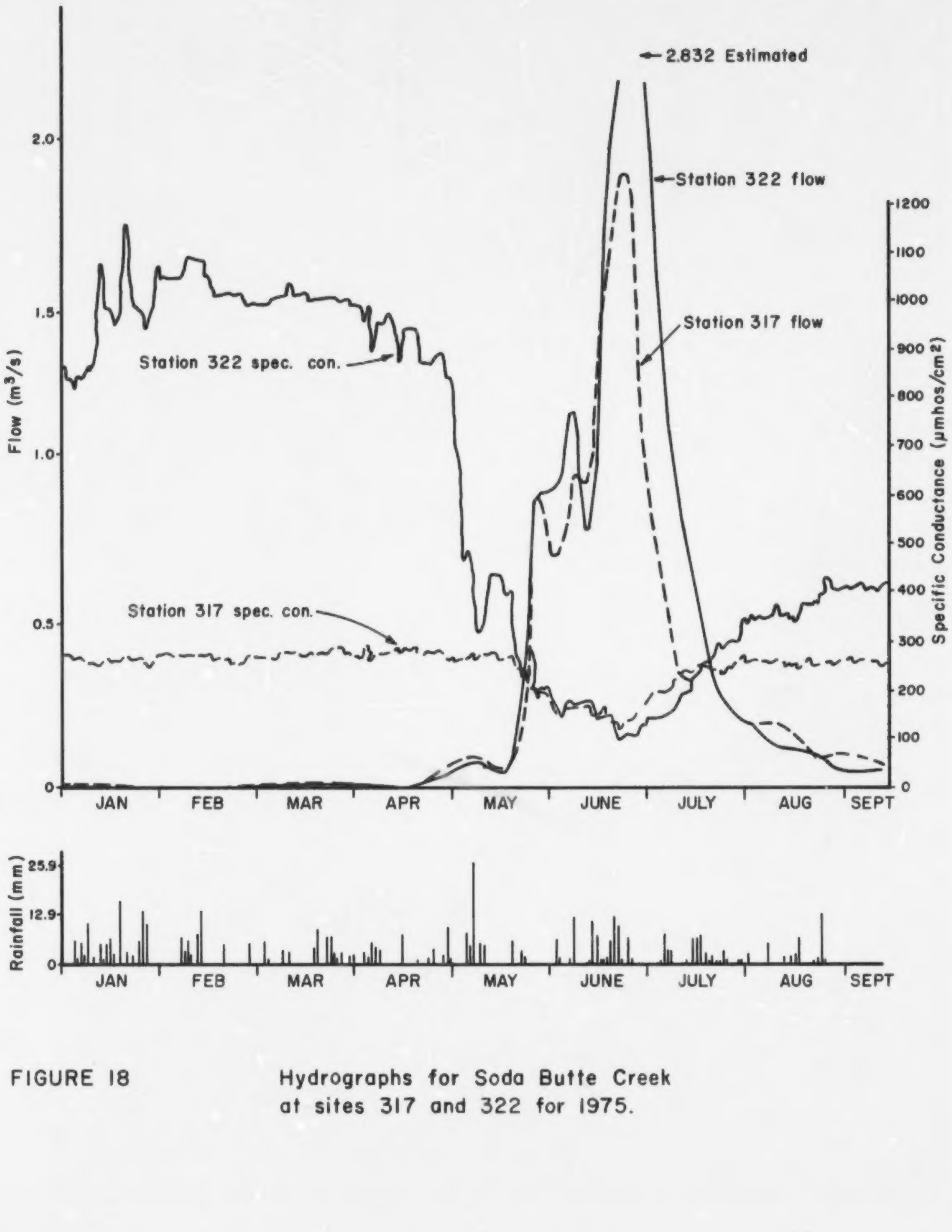
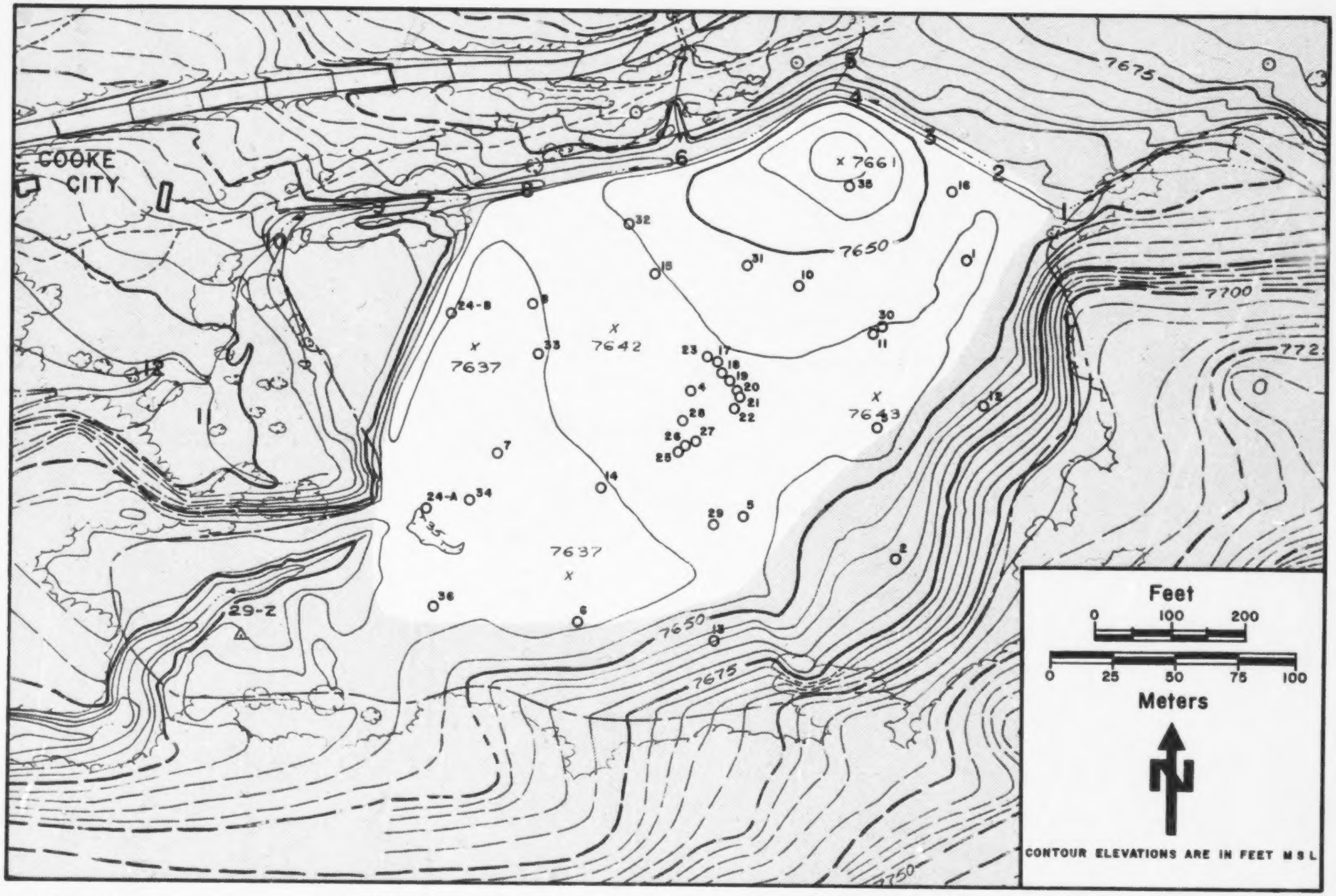


FIGURE 18 Hydrographs for Soda Butte Creek at sites 317 and 322 for 1975.


COOKE CITY
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10
12
29-Z
7675
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7661
7642
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7637
7750
24-B
24-A
Feet
0
100
200
Meters
0
25
50
75
100
CONTOUR ELEVATIONS ARE IN FEET M S L

FIGURE 19 Location of flow measurement sites (large numbers), McLaren mill site (July 21, 1975).

streamflow. Due to the winter freeze up of the stilling well and the weir destruction during runoff, only the overall yearly cycle based on weekly and semimonthly measurements can be evaluated. The base-flow period for Soda Butte Creek has been marked on a semilogarithmic hydrograph (Figure 20, page 60); the portions marked V1 and V2 represent the groundwater flow that sustains or supplements the creek flow from August until the following May at sites 317 and 322, respectively. This groundwater contribution, which is measurable as surface water flow, represents only 2 to 4 percent (V2) of the total measured surface water flow at the point studied (site 322). In contrast, the base flow at site 317 is roughly 10 percent (V1) of the total measured surface water flow. The difference is attributed to the steeper stream gradient in the upper reaches of Soda Butte Creek, which we believe prevented the development of thick gravel beds, compared with those developed between sites 317 and 322 (Miller Creek seems to have contributed significantly to the buildup of gravel beds more than 12 m thick locally). The difference in ratios of base flow to total surface flow at sites 317 and 322 further substantiates the premise that this stretch of the creek is a natural zone of groundwater recharge. It is believed that the total water outflow from the drainage basin at site 322 must be 1.5 to 3.0 times greater than the measured flow at site 322; the best estimate based upon the available data is that the annual groundwater flow is approximately equal to the annual surface water flow.

TABLE 9. FLOW MEASUREMENTS (m^3/s) AROUND McLAREN MILL TAILINGS POND, JUNE 21, 1975.

Site	Soda Butte flow	Previous station flow plus inflow	Tributary inflow	Loss between station
1	0.89	---	---	---
2	0.71	0.89	---	0.18
3	0.68	0.71	---	0.17
4	0.69	0.68	---	-0.01 (gain)
5	---	---	0.01	---
6	0.65	0.70	---	0.05
7	---	---	0.20	---
8	0.85	0.85	---	-0.00
9	0.97	0.85	---	-0.12 (gain)
10	0.76	0.97	---	0.21
11	---	---	0.04	---
12	0.75	0.80	---	0.05

Total inflow (stations 1, 5, 7, and 11) = 1.14 m^3/s
Net loss is 0.39 m^3/s at station 12

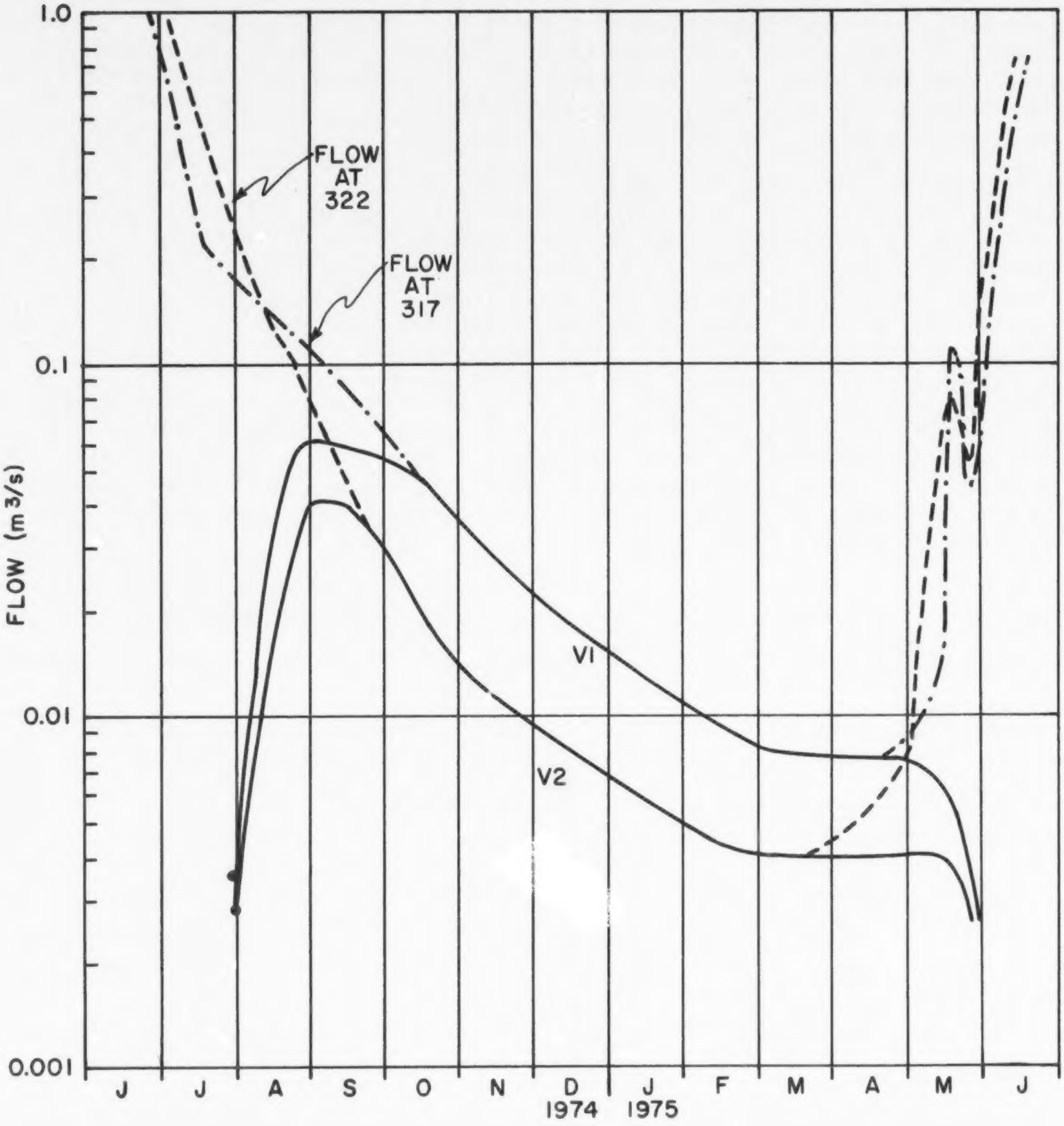


FIGURE 20 Semilogarithmic plot of Soda Butte Creek hydrographs showing base flow components VI and V2 for sites 317 and 322, respectively.

Groundwater Investigations. The groundwater study was restricted to the tailings pond, with primary emphasis on: (1) water movement within the tailings, (2) avenues of recharge to the tailings materials, and (3) the movement of groundwater out of the tailings. Observation wells were installed to permit measurement of the water level (Appendix E). Well-injection and surface-infiltration tests were performed to determine tailings transmissivities and infiltration rates. Results of the 1975 field season generally provided additional data to support previous interpretations (Higgins, 1974; Wallace et al., 1975) except that surface infiltration is no longer believed to play a significant role in recharging the tailings if the surficial materials have not been disturbed.

The surface-infiltration test showed that prior to field capacity of the soil the infiltration rate is 3.239 liters meters^{-2}hour^{-1}. Once the soil is brought up to field capacity, further infiltration should be negligible.

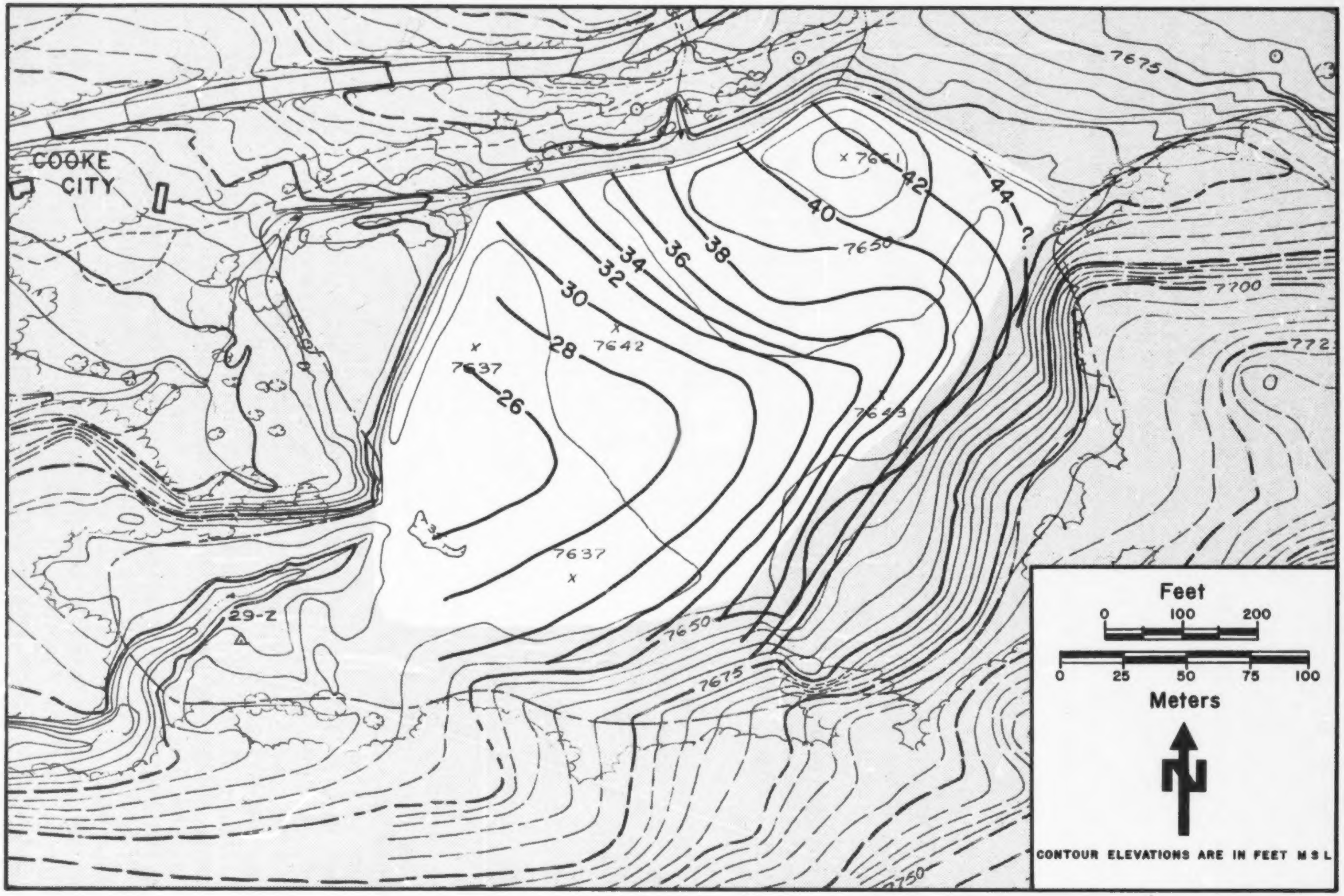
Well 27 was used as an injection hole to evaluate the hydrologic character of the tailings. The well extended 4.2 m below land surface (tailings from 0.9 to 4.2 m).

From the results of the slug injection test, it is believed that the tailings at this site can be represented by a transmissivity value between 12 and 37 l/m/day, which means the tailings material would be classified as a poor aquifer.

Water-table maps (Figures 21-25, pages 62-66) were constructed from the measured water levels in the wells (Appendix H) to interpret the direction of flow within the tailings. A flow map will be presented later (Figure 32, page 78), once the quality data have been presented.

Water Chemistry

The surface water chemistry of the mill area differs from that of the mine areas in that the creek water is not acidic, the aluminum concentration is one or two orders of magnitude lower, and the copper and zinc values are considerably lower (Appendix E). The major problem seems to be the dissolved iron content, which increases from less than 0.1 mg/l during the flood stage recession to almost 50 mg/l during the low winter flow when the tailings pond loss is diluted by as little as 1.5 to 2.0 volumes of creek water. This relationship is depicted graphically in Figure 26, page 66, which is a log-log plot of flow versus sulfate concentration. The sulfate concentration in samples collected above the mill site (317) averages approximately 10 mg/l regardless of the streamflow. Similarly, the discharge at the culvert weir, which drains the tailings (321), has an average sulfate concentration of about 700 mg/l, which does not vary greatly as a function of flow. At the sampling site below the tailings (322), the sulfate concentration is definitely related to flow. The ideal dilution curve, assuming a fixed quantity and composition of pollutant mixing with a variable quantity of fixed composition dilutant, behaves somewhat differently than the preceding figure. The initial dilution (as much as fivefold) is very nearly linear and has a slope of -1.0, but with an increasing amount of dilutant (flow in Figure 26, page 67)


COOKE CITY
7675
x 7661
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44
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40
7650
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36
34
32
30
28
26
x 7642
x 7637
7643
7700
772
29-Z
7637 x
7650
7675
7750
Feet
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100
200
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25
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75
100
Meters
N
CONTOUR ELEVATIONS ARE IN FEET MSL

FIGURE 21 Water table map of the McLaren mill site (May 21, 1974).

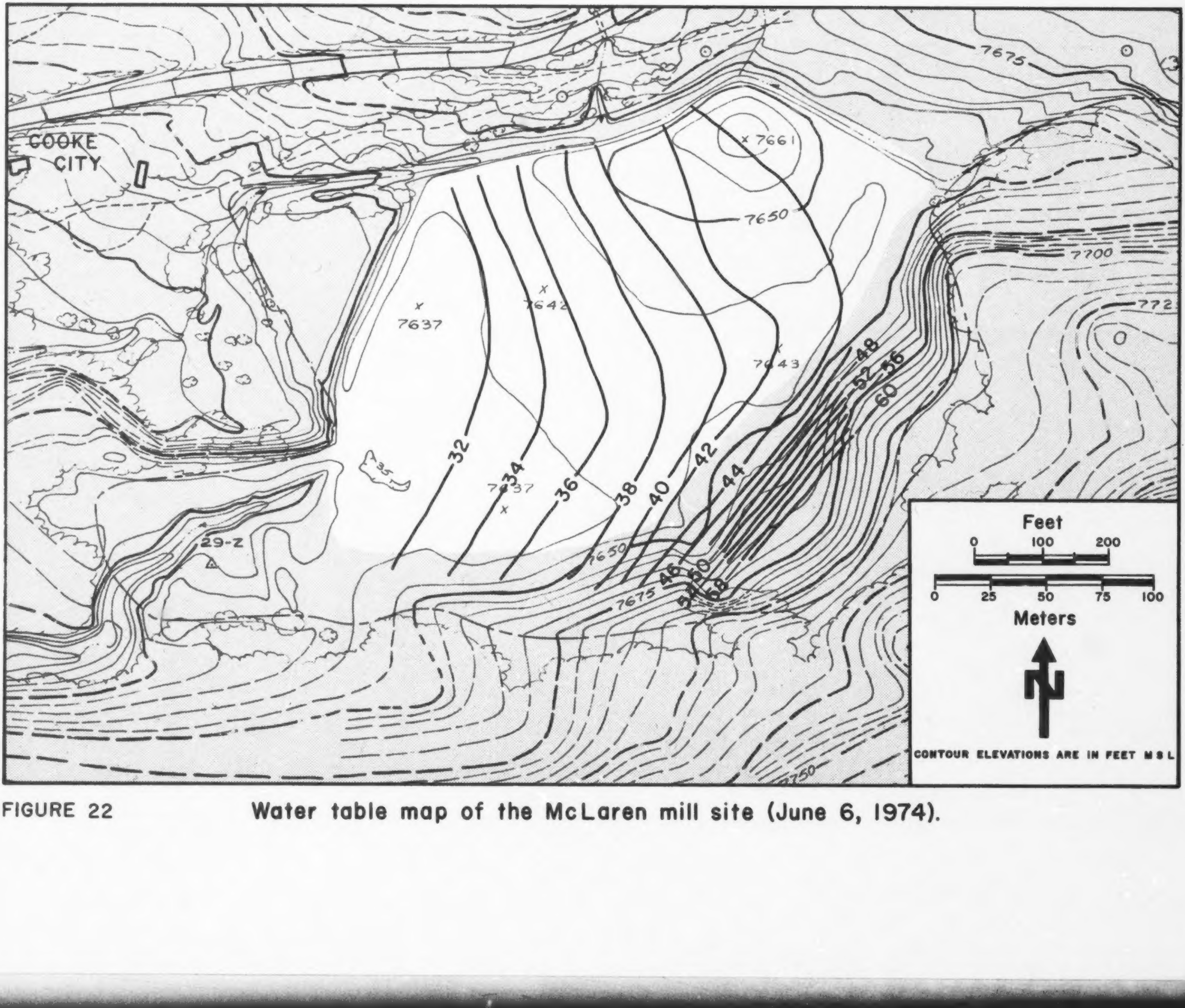
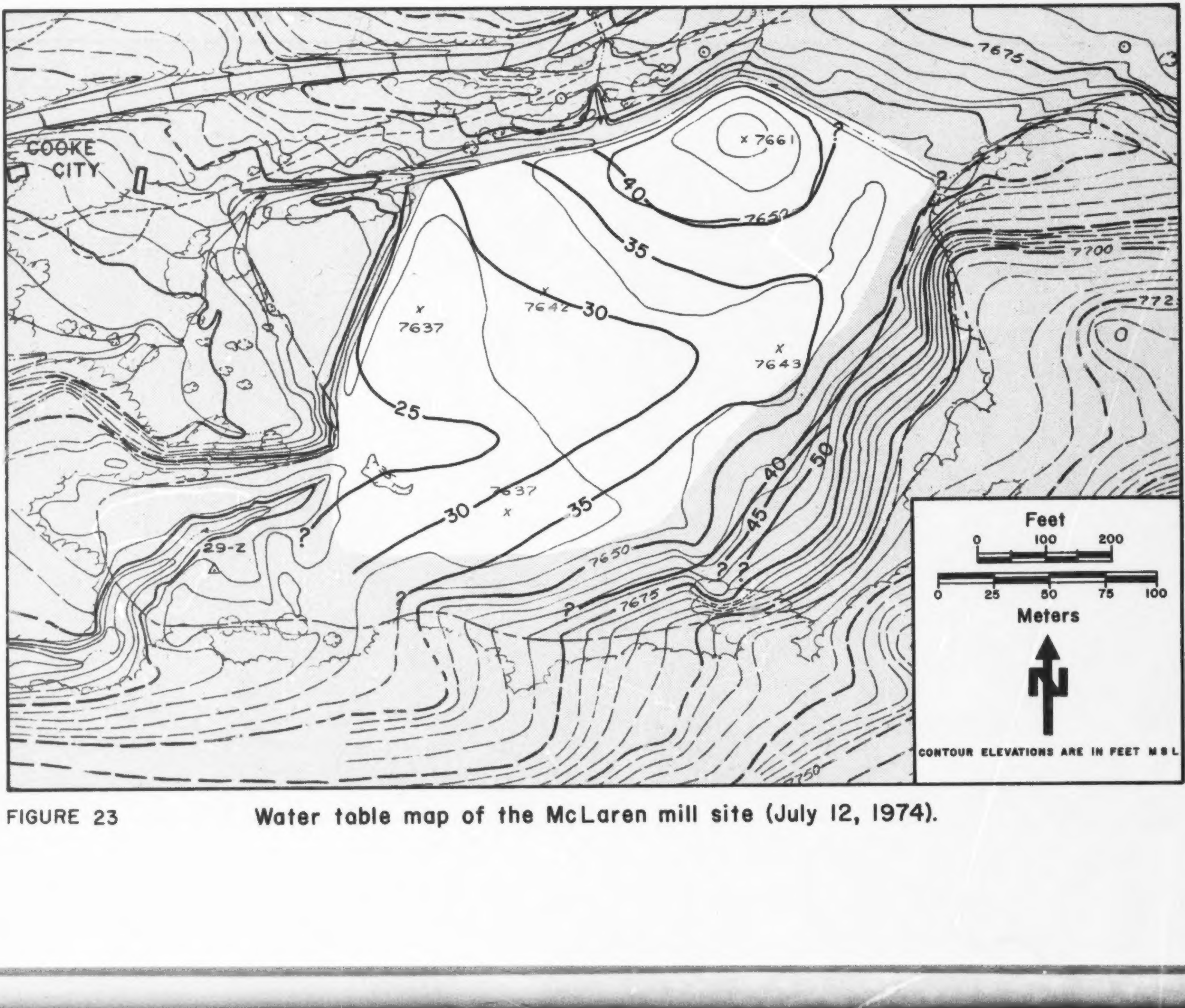

COOKE CITY
7675
7661
7650
7700
772
7637
7642
7643
7637
35
29-Z
7650
7675
7750
32
34
36
38
40
42
44
46
48
50
52
56
58
60
Feet
0
100
200
0
25
50
75
100
Meters
N
CONTOUR ELEVATIONS ARE IN FEET M S L

FIGURE 22 Water table map of the McLaren mill site (June 6, 1974).


COOKE
CITY
7675
x 7661
7650
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35
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25
x 7642
x 7637
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7637 x
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45
40
50
?
29-Z
7700
7725
7750
Feet
0
100
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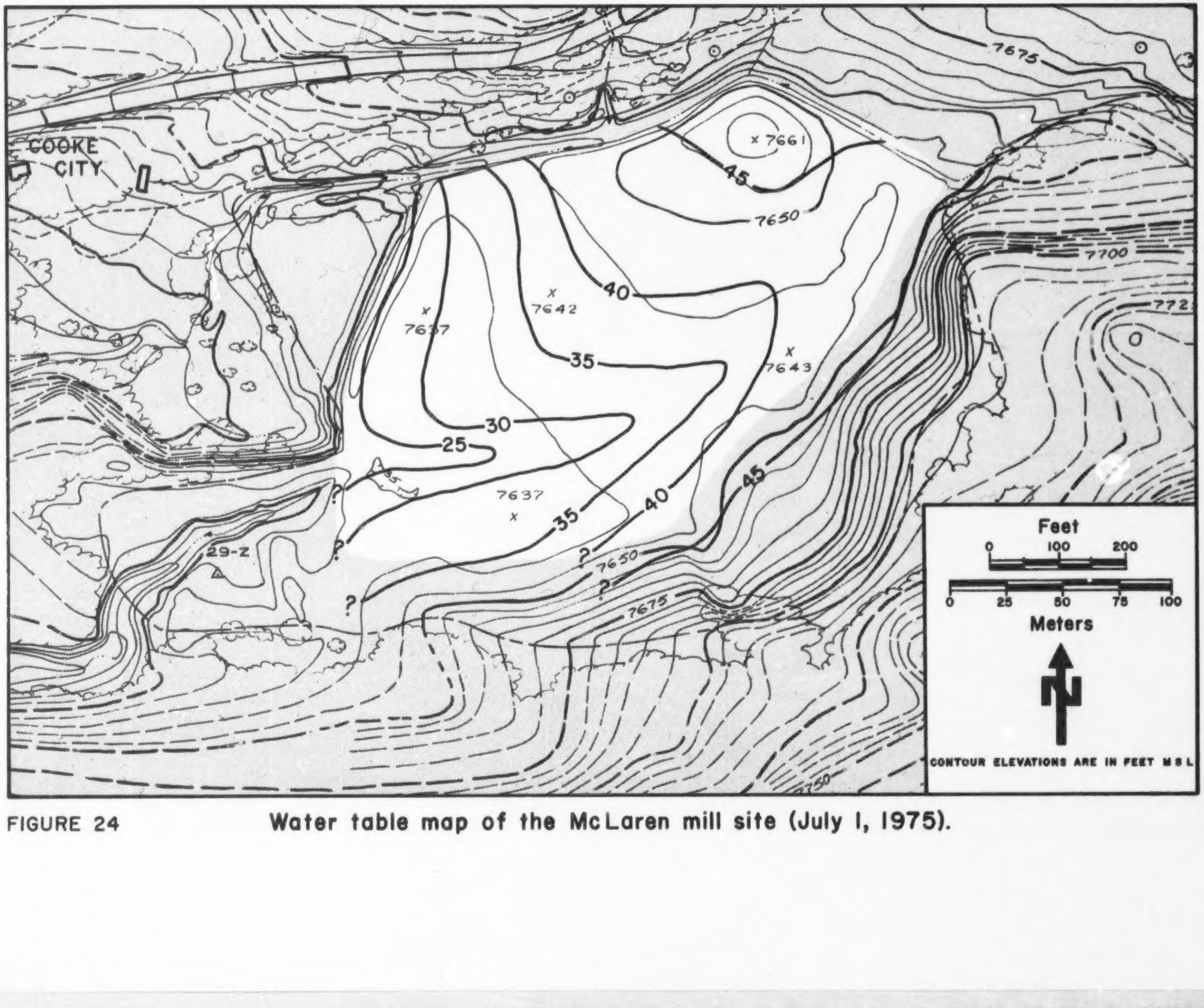
100
Meters
CONTOUR ELEVATIONS ARE IN FEET M S L

FIGURE 23 Water table map of the McLaren mill site (July 12, 1974).


COOKE CITY
7675
7700
772
7661
45
7650
40
7642
7637
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7643
7637
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40
45
?
7650
7675
29-Z
7750
Feet
0
100
200
0
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50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET MSL

FIGURE 24 Water table map of the McLaren mill site (July 1, 1975).

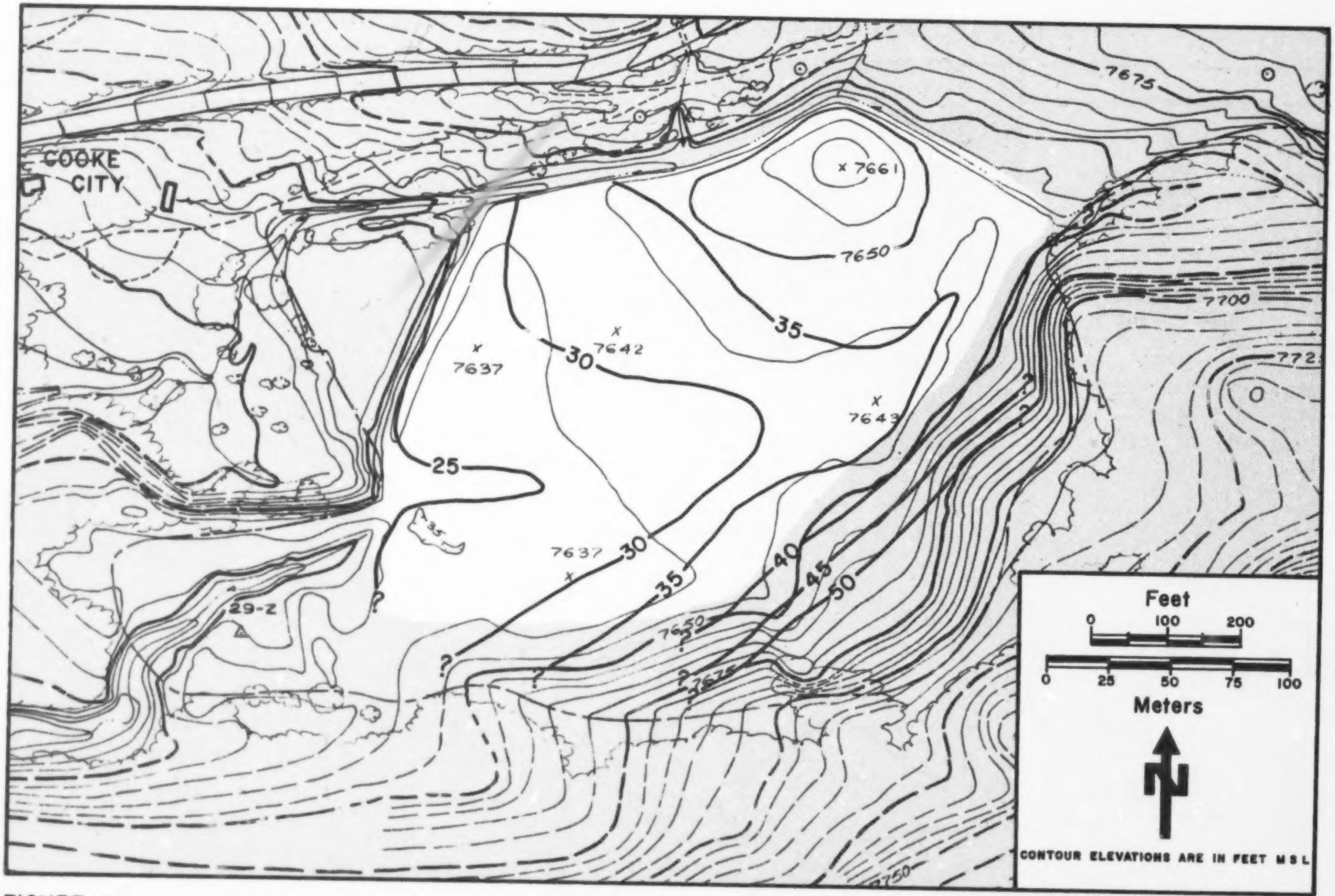

COOKE CITY
7675
x 7661
7650
35
x 7642
30
x 7637
25
35
x 7643
7637
30
35
40
45
50
7700
772
7650
7675
7750
29-Z
?
Feet
0
100
200
0
25
50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET MSL

FIGURE 25 Water table map of the McLaren mill site (September 9, 1975).

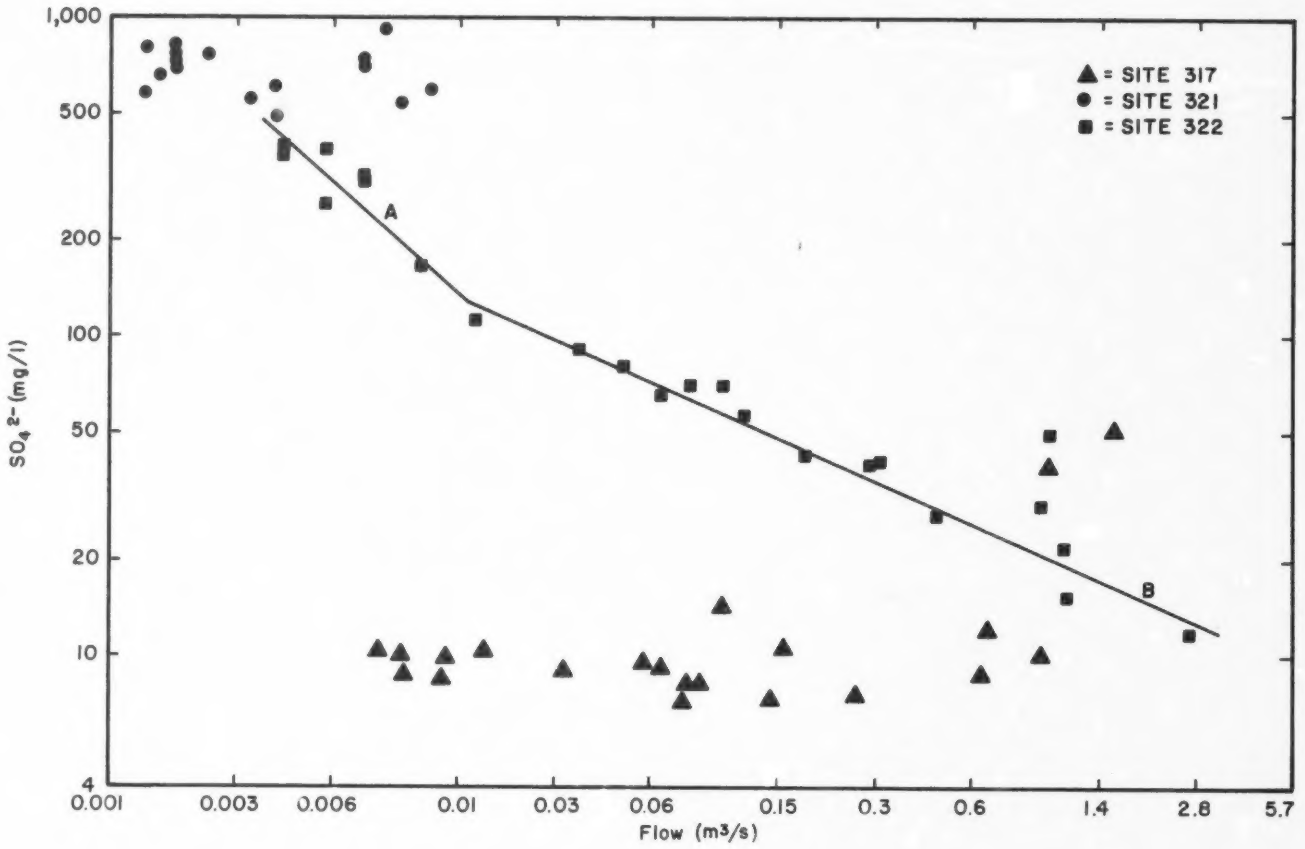


FIGURE 26 Flow versus sulfate plot for sites 317, 321, and 322.

the straight line becomes a curve, which asymptotically approaches the value of the dillutant concentration. The departure of site 322 data from this ideal case results from two complicating factors: (1) the volume and composition of the tailings effluent is not constant, the variable volume being the more significant problem, and (2) during periods of high flow in Soda Butte Creek, a significant fraction of the water is derived from Miller Creek, which has a higher average sulfate content (15 mg/l) than the Soda Butte Creek water.

The major pollutant in Soda Butte Creek is iron. Dissolved iron seems to be the dominant factor affecting trout mortality (Knudson and Estes, 1976). The concentration of dissolved iron in Soda Butte Creek cannot be solely related to flow or to sulfate concentration. Plots of these factors show too much scatter to permit meaningful results from dependent variable regression analysis of one factor at a time. Multiple regression techniques could be used to evaluate the effects of reclamation. Factors that should be considered include: flow, pH, distance from source, water composition (especially SO_4^{2-} and HCO_3^-), redox potential, suspended sediment, total recoverable iron (iron in water and sediment released by treating the raw sample with 1 volume percent concentrated acid, preferably HNO_3), and creek stage (the high iron values associated with high flow are usually found during the rising stage, probably resulting principally from the transport of colloidal size $Fe(OH)_3$ and dissolution of $KFe_3(SO_4)_2(OH)_6$). The latter material (jarosite) is somewhat soluble in meltwater runoff or precipitation despite its thermodynamic solubility constant of approximately 10^{-101} (D. Langmuir to J. Sonderegger, December 1975, personal communication), and could contribute to the formation of colloidal iron of fine enough size to be classified as dissolved according to the following reaction.

$$KFe_3(SO_4)_2(OH)_6 + 3\ H_2O = K^+ + 3\ Fe(OH)_3 + 2\ SO_4^{2-} + 3\ H^+ \qquad (1)$$

This would help to explain Higgins' (1974, page 14) observation that rainfall upon the mill site resulted in the rapid formation of acidic, high iron, sulfate runoff water. Jarosite would be expected only in conjunction with waters right in sulfate, as a secondary mineral. Most occurrences are related to acid mine drainage from shafts, spoils, and tailings, or natural drainage from zones of intense sulfide mineralization.

The area's more significant source of "dissolved" and total recoverable iron is probably the very fine iron precipitate, which is moved from the land surface only during hard rainfall and from stream channels only during high flow periods. At site 317, above the tailings pond, dissolved iron values are low ($\leq$ 0.03 mg/l) during February, March, and April. As the runoff starts and streamflow increases, the dissolved iron concentrations start to rise, reaching a maximum before the creek crests. Data concerning total recoverable iron are available starting in June 1975 and suggest a similar pattern. The sample for July 30, 1975, was collected at the cessation of a brief but intense rainfall. The high total recoverable iron value (16.9 mg/l) is indicative of suspended sediment transport (52.7 mg/l) and is believed to result from the transport of ferric hydroxide, because the iron, determined by difference, constitutes 32 weight percent of the suspended material.

The data from below the tailings pond (site 322) follow a different pattern, owing to the influence of the tailings effluent. Dissolved iron decreases with increasing flow, with one exception. The July 2, 1975 sample is anomalously high in all metals, probably contained in fine colloids; the total suspended solids content was 631.56 mg/l, the stage was rising, and the flow (2,700 lps) was near the peak. The decrease in iron is attributed to dilution and to increased aeration and pH, factors that increase the rate of ferric hydroxide formation from dissolved ferrous iron (Stumm and Morgan, 1960, p. 534). The data for total recoverable iron suggest a bimodal distribution, with higher values during low flow, and during high flows associated with rising-limb runoff or times of intense precipitation.

The chemical character of waters from the mill-site observation wells (Appendix E), the seeps at the toe of the tailings dam, and the spring (approximately where the old stream culvert is reported to have passed through the tailings dam) is related to flow through the tailings material and the reactions that occur during that passage. The key points are:

(1) Iron (both total recoverable and dissolved) and sulfate concentrations are considerably lower at the culvert weir and seep sites than in the wells at the lower end of the tailings pond.

(2) The field pH at the culvert weir spring is considerably higher than that of the lower wells; the field pH of the seeps at the toe of the dam is as low as the pH of the tailings well waters or lower.

(3) The specific conductance and total dissolved solids values are smaller for the culvert weir samples than for samples from the lower wells.

These facts are interpreted as the result of the mixing of dissimilar waters to explain the chemical composition of samples from the culvert weir site. Consideration of a system in which only the tailings groundwater appears at the culvert weir spring requires one or more precipitation reactions, which reduce the iron and sulfate concentrations while increasing the pH (i.e., consuming hydrogen ions). In general, the weathering and dissolution reactions for oxide, carbonate, and silicate minerals consume hydrogen ions and increase the concentration of dissolved constituents, whereas the precipitation or secondary formation of these minerals lowers the concentrations of dissolved constituents but releases hydrogen ions to the aqueous phase. The precipitation of iron as a hydroxide would lower the pH and would not alter the sulfate content. Sulfate reduction by a reductant such as organic carbon

$$Fe^{+2} + CH_4 + SO_4^{-2} = H_2CO_3 + FeS + H_2O \qquad (2)$$

would reduce both iron and sulfate concentrations, but organic material in the tailings is not sufficient nor is the redox potential of the water issuing from the spring low enough for troilite (FeS) or pyrite (FeS_2) to be stable relative to ferric hydroxide. The precipitation of jarosite utilizing both particulate and dissolved iron would provide the desired results

$$2\ K^+ + Fe^{3+} + 5\ Fe(OH)_3 + 4\ SO_4{}^{2-} = 2\ KFe_3(SO_4)_2(OH)_6 + 3\ OH^- \qquad (3)$$

but dissolved potassium is insufficient for this reaction to be significant, and the weathering product (kaolinite) resulting from the destruction of microcline and muscovite to provide the necessary potassium ions was not noted in the clay analyses for hole 24A.

The preceding discussion was not meant to deny the possibility of any of the reactions considered from occurring to some extent. If an average flow of 2.8 lps and an iron content of 125 mg/l are assumed for the spring outflow, then more than 11 metric tons of iron is released annually at this site, and two to eight times this amount must be left behind as a precipitate of some sort. The absence of identifiable products of these reactions suggests that they are not the major factor controlling the chemical composition of the tailings effluent issuing from the culvert weir spring. Thus, a mixing model consistent with chemical quality of the well waters must be considered.

An isopleth is defined as a line connecting points of equal size or abundance; maps showing the magnitude of the pH, specific conductance, sulfate concentration, and dissolved iron concentration are presented to facilitate the discussion of water movement, mixing, and the concomitant chemical reactions. The weathering of pyrite may be dipicted as (Appendix D)

$$FeS_2 + 7/2\ O_2 + H_2O = Fe^{2+} + 2\ SO_4{}^{2-} + 2\ H^+ \qquad (4)$$

under moderately reducing conditions similar to those encountered in the tailings. The reaction rate has been shown to be controlled in large part by the availability of the oxidant (usually O_2). Therefore, waters with lower pH values should represent areas where oxygen-bearing waters are introduced at a sufficient rate to more than offset weathering reactions, which consume hydrogen ions. This approach assumes that pyrite concentrations and permeabilities are approximately constant; these assumptions are known to be roughly approached at best within the tailings, although sulfur content is fairly uniform (Table 7, page 52). The map of pH values (Figure 27, page 71) indicates a trough-shaped feature similar to that found on the water-table maps. This area of lower pH is believed to represent significant water input from the gravel beneath the tailings, predominatly streamflow loss to the gravel but also a groundwater contribution from the higher ground to the south.

The specific conductance map (Figure 28, page 72) shows two zones of highly mineralized water separated by a less mineralized zone. This distribution is believed to result from dilution and from permeability

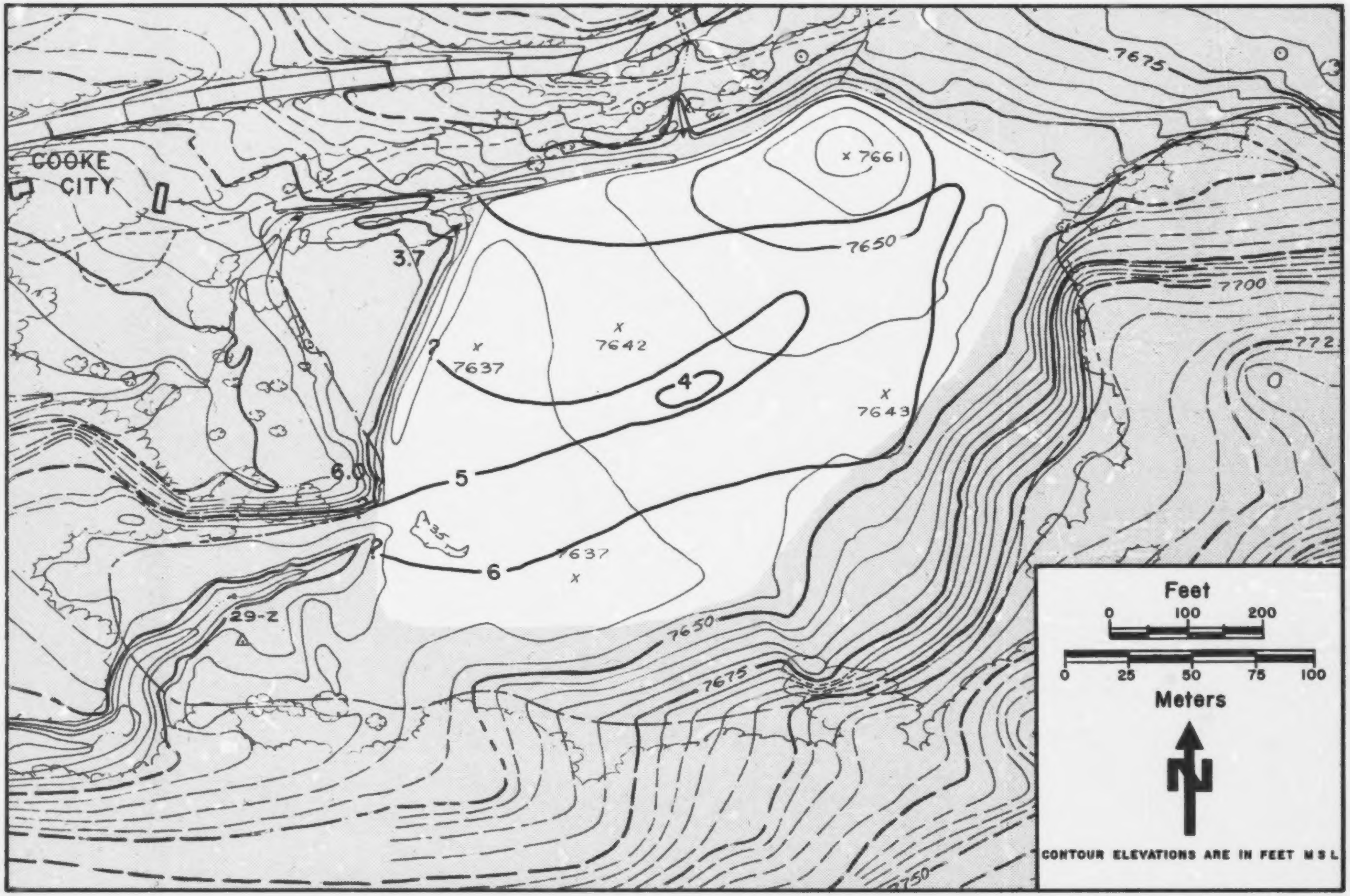
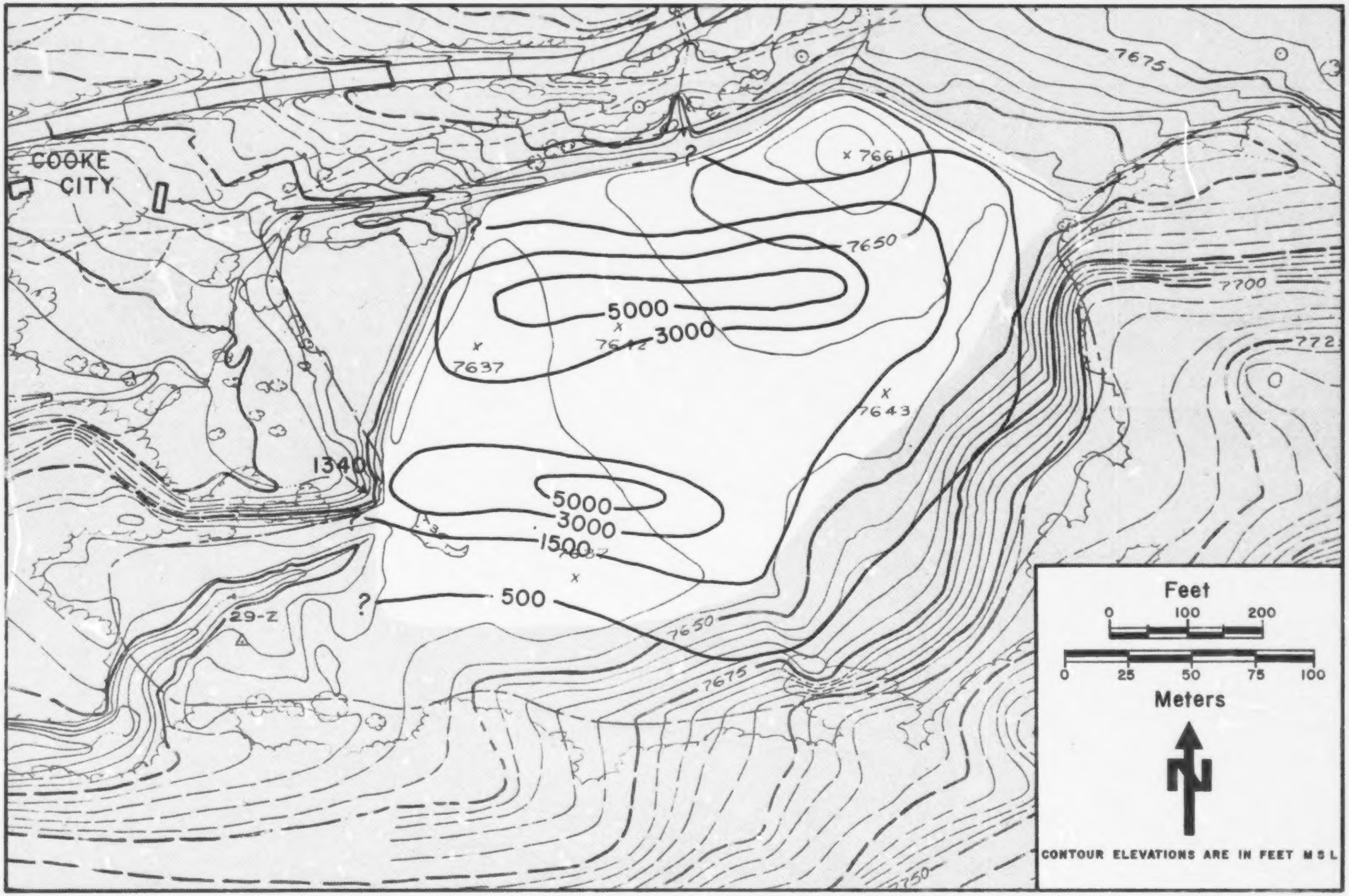

COOKE CITY
3.7
6.0
?
7637
7642
7643
7661
7637
4
5
6
35
29-Z
7650
7675
7700
772
7750
Feet
0
100
200
0
25
50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET MSL

FIGURE 27

Isopleth map of field pH values from wells at the McLaren mill site (July 2, 1975).


COOKE CITY
7675
7661
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7725
5000
3000
7637
7642
7643
1340
5000
3000
1500
7637
500
?
?
29-Z
7650
7675
7750
Feet
0
100
200
0
25
50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET MSL

FIGURE 28 Isopleth map of laboratory specific conductance (μmhos/cm^2) from wells at the McLaren mill site (July 2, 1975).

differences. According to Higgins (1974), wells 4, 10, and 11 penetrated 0.6, 0.5, and <0.03 m, respectively, of the underlying gravel, which suggests that dilution is probable at wells 4 and 10, and barely possible at well 11. Well 10 has a very high specific conductance, indicative of very limited mixing with water from below. Dilution by mixing is probably occurring at well 4; well 11 is indeterminate as its location is near the margin of the tailings, and the gradient between the stream and the hole bottom is still fairly steep, suggesting a small artesian head in the gravel.

Sulfate is the dominant anion in the mineralized water and is believed to behave almost conservatively. The amount of sulfate lost from the aqueous phase by the precipitation of gypsum, jarosite, and other sulfate minerals should be minor, for reasons stated earlier. Consequently, the map of sulfate concentration isopleths (Figure 29, page 74) resembles the specific conductance map. The major difference in the maps is related to the alkalinity/sulfate ratios of wells along the southern and eastern margin of the tailings; in these wells, the bicarbonate ion contributes significantly to the specific conductance. The waters from these wells have not been extensively altered by chemical reactions with sulfide minerals.

The map of the dissolved iron isopleths is presented (Figure 30, page 75) primarily because of the significance of iron in this study. The data suggest the same basic configuration, but the iron values show extreme seasonal variation in some of the wells (3, 5, and 6 especially) as listed in Appendix E. These wells are near the old channel occupied by Soda Butte Creek prior to the construction of the tailings dam (E. Nott to J. Wallace, July 1974, personal communication). The high iron values in winter suggest that the old channel is partly blocked below well 6 and that a perched water table forms within the streambed during the winter when the water table in the gravel would be at its lowest level in the yearly cycle.

Discussion

Groundwater Flow in Tailings. The depiction of the groundwater flow pattern within the tailings material depends upon the interpretation of the hydraulic characteristics of the units present and how they react in the dynamic situation. Figure 31, page 76, depicts stratigraphy at the tailings pond. The crucial factor is the presence and nature of a boundary condition between the tailings and the underlying gravel. If a thick, relatively impermeable ferric hydroxide cementing zone were present everywhere at the base of the tailings, the tailings material would constitute a semi-isolated hydrologic system, and flow within the tailings would be roughly normal to the water-table contours. Wells that partly or completely penetrate such a barrier, however, will measure partly or completely the effect of water levels or piezometric pressures in the underlying gravel, resulting in lower water levels during most or all of the year. Even in the absence of the hydroxide cementing material, a distinct permeability difference between the two layers constitutes a hydrologic boundary condition of considerable significance. In both cases, the groundwater within the tailings will migrate laterally, but a

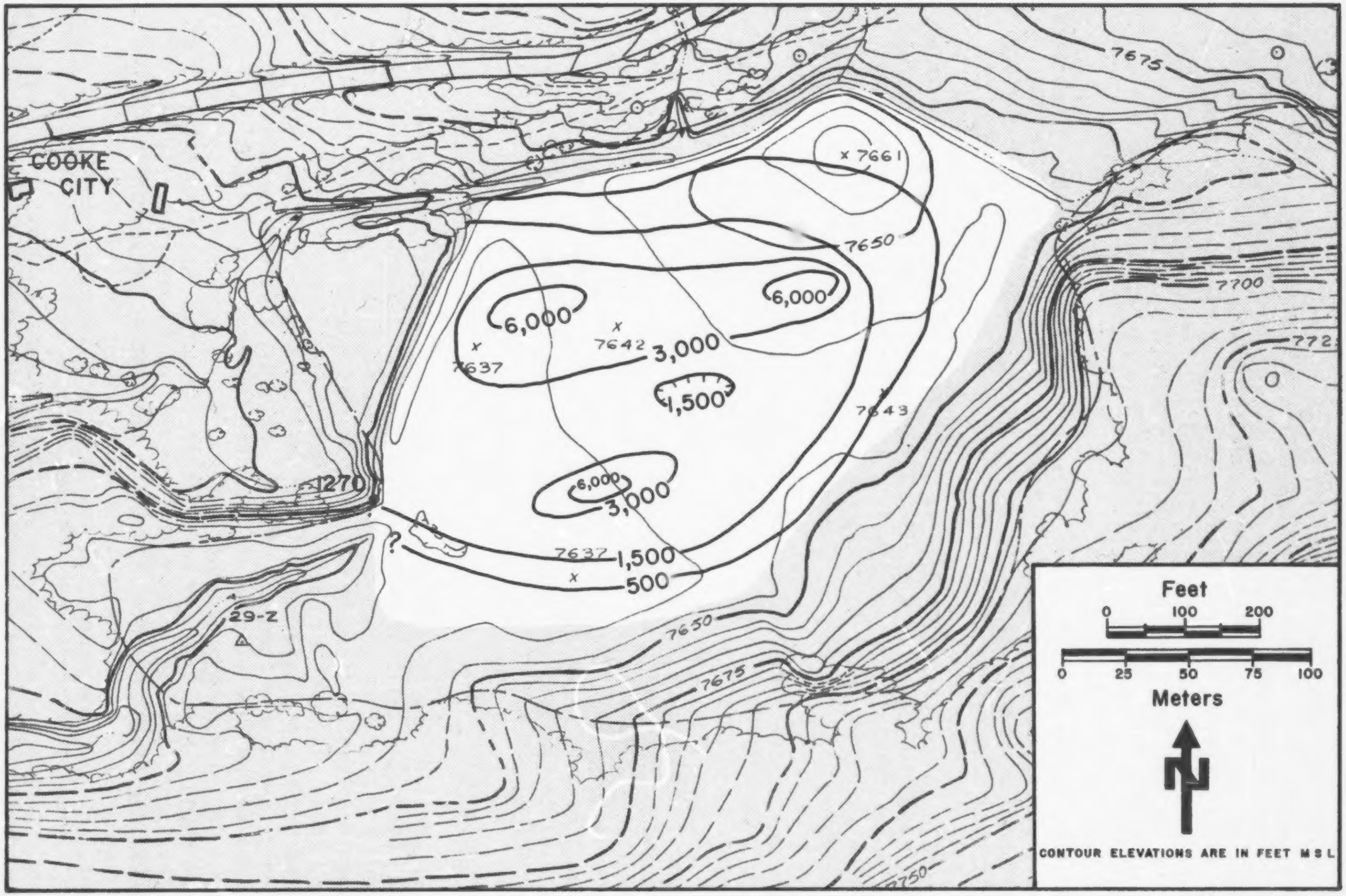

COOKE CITY
7675
7700
7725
7661
7650
7643
7642
7637
7637
6,000
6,000
6,000
3,000
3,000
1,500
1,500
500
7650
7675
7750
1270
29-Z
Feet
0
100
200
0
25
50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET M S L

FIGURE 29 Isopleth map of sulfate concentration from wells at the McLaren mill site (July 2, 1975).

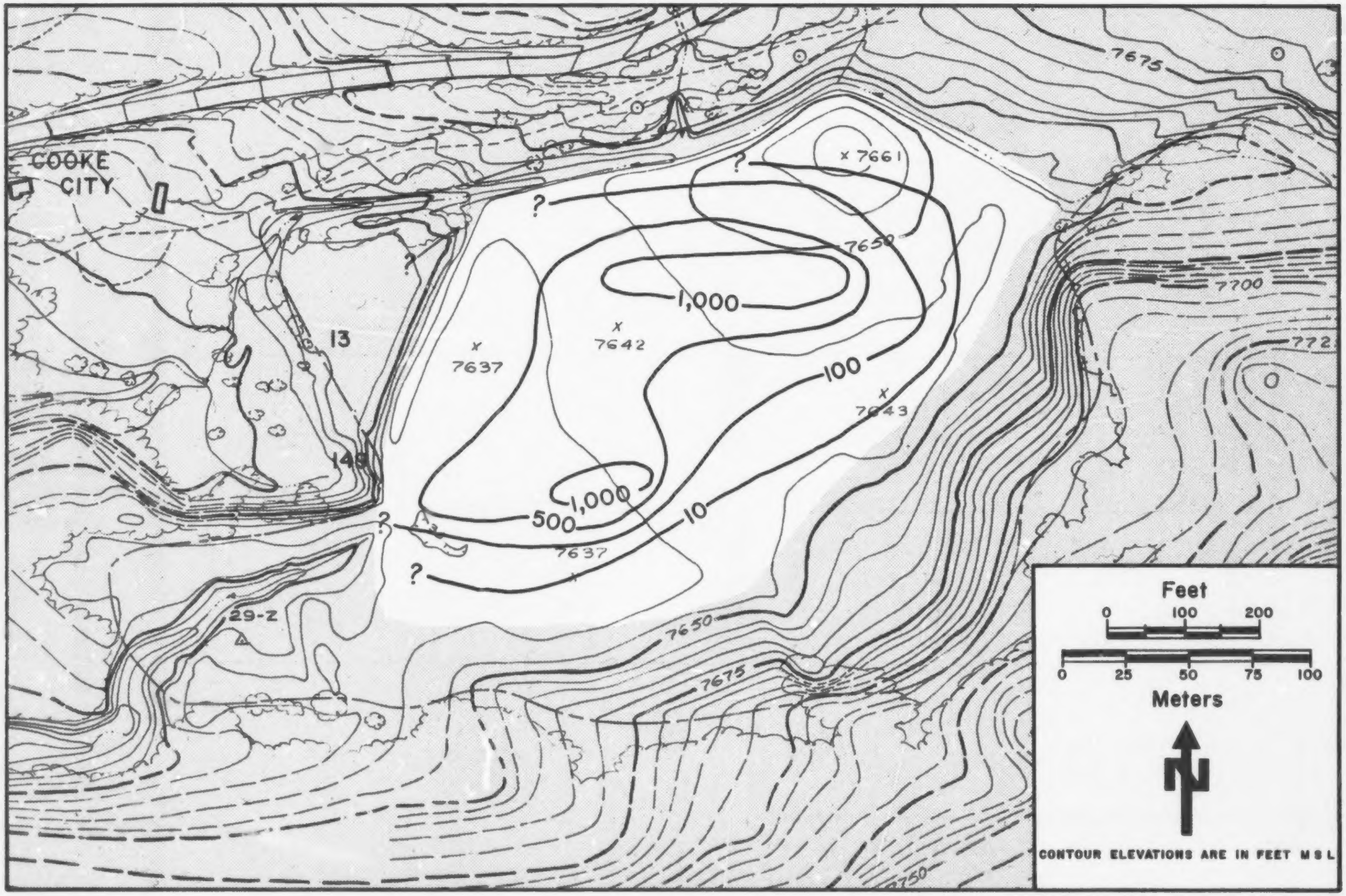

COOKE
CITY
13
148
29-Z
7675
7700
772
7650
7750
x 7661
x 7642
x 7637
x 7643
7637
1,000
1,000
500
100
10
?
Feet
0
100
200
0
25
50
75
100
Meters
N
CONTOUR ELEVATIONS ARE IN FEET M S L

FIGURE 30

Isopleth map of dissolved iron concentration from wells at the McLaren mill site (July 2, 1975).

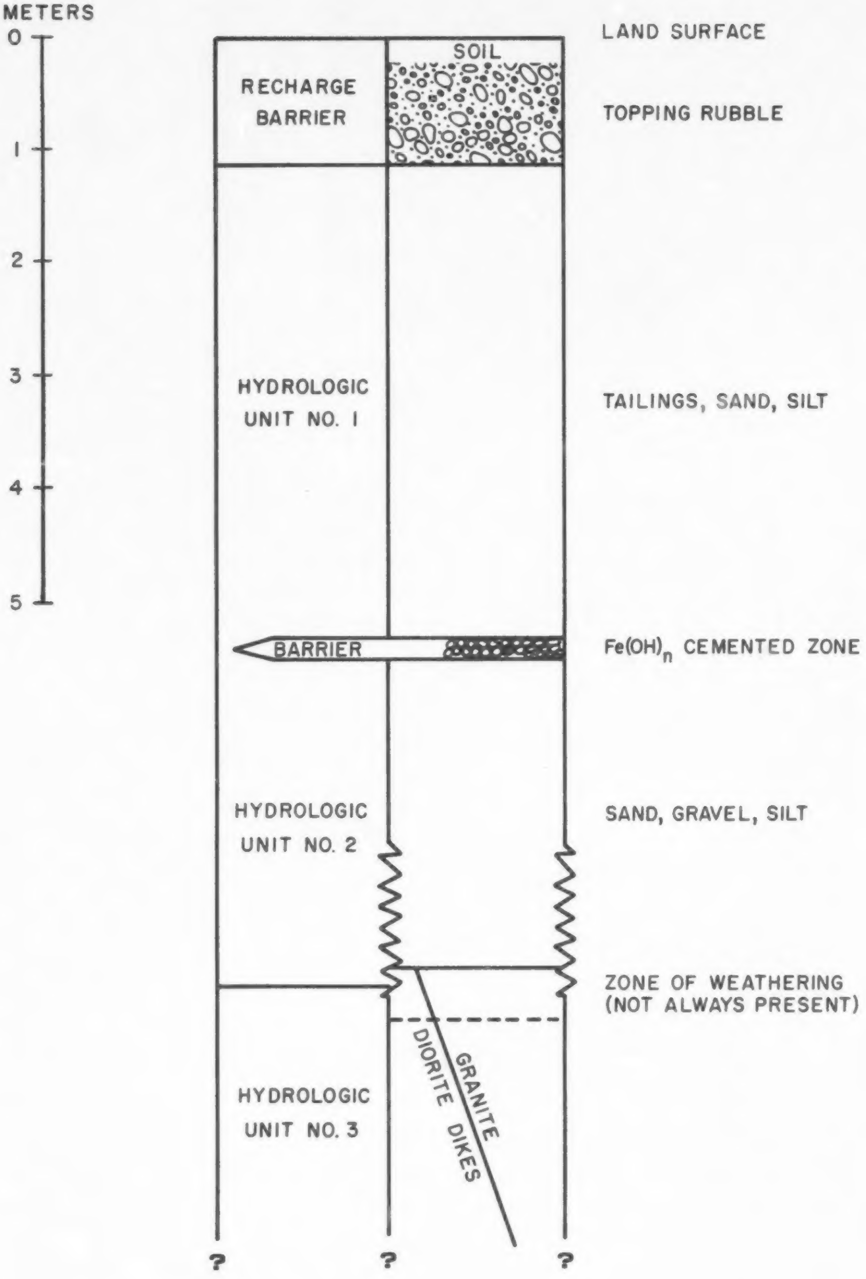

METERS
0
1
2
3
4
5
LAND SURFACE
SOIL
RECHARGE BARRIER
TOPPING RUBBLE
HYDROLOGIC UNIT NO. 1
TAILINGS, SAND, SILT
BARRIER
Fe(OH)n CEMENTED ZONE
HYDROLOGIC UNIT NO. 2
SAND, GRAVEL, SILT
ZONE OF WEATHERING
(NOT ALWAYS PRESENT)
HYDROLOGIC UNIT NO. 3
GRANITE
DIORITE DIKES
?
?
?

FIGURE 31 McLaren tailings pond-diagrammatic vertical section.

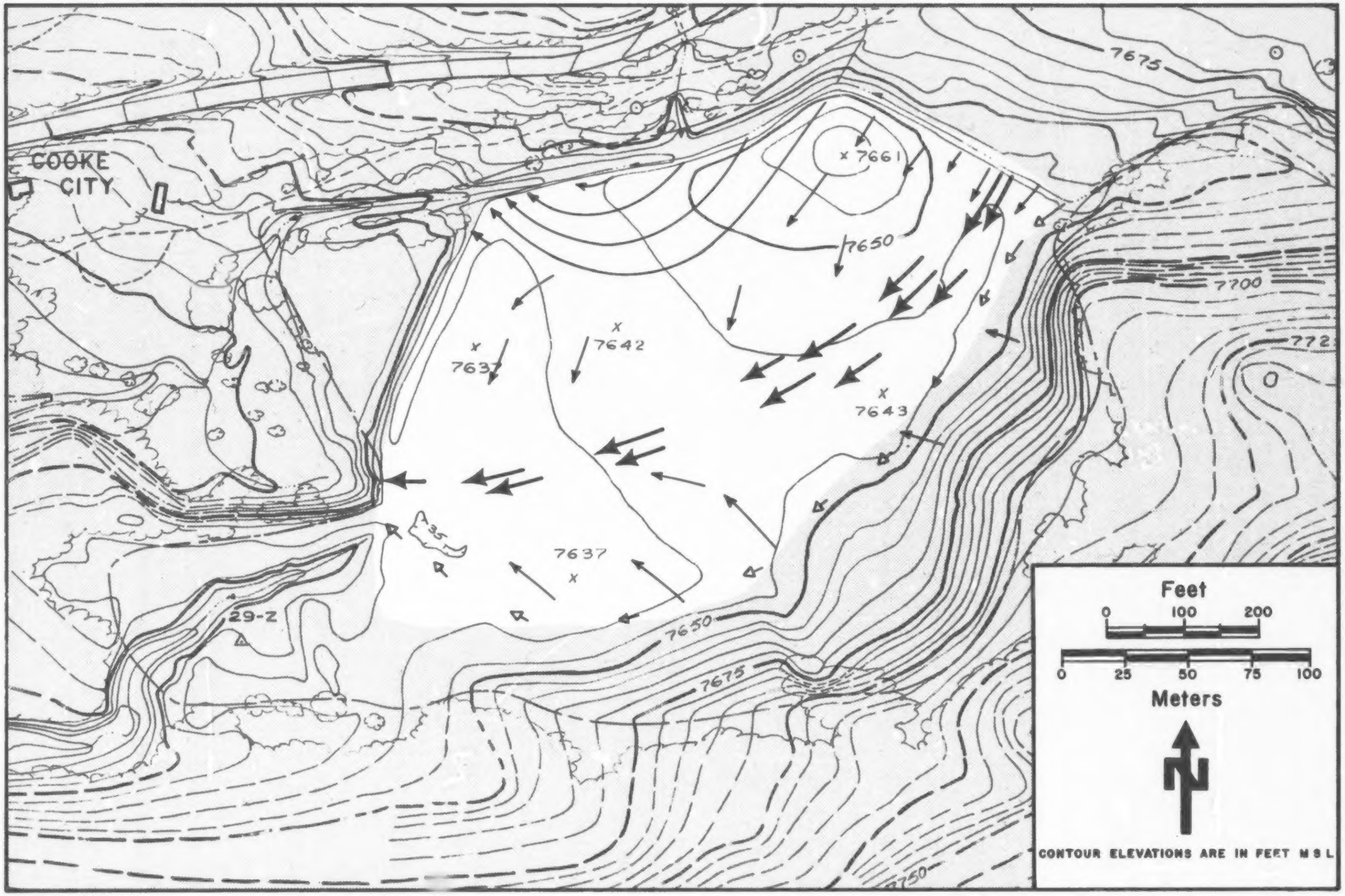
significant factor is the loss of water to the gravel during the fall, winter, and spring seasons. The drilling of wells on the tailings has undoubtedly made the recharge problem worse, in that surface meltwater has recharged the tailings at most wells, by drainage down the hole around the outside of the casing and even by direct flow down the casing (wells 1 and 6, in particular). Furthermore, the well construction, which has disturbed or eliminated the boundary between the tailings and the gravel in some places, permits the gravel zone to act as a direct recharge source to higher sections of the tailings.

The relative effect of this disturbance can be partly documented for wells 25, 26, and 27, which were drilled, gravel packed, and flushed on September 8, 1975. Their measured depths were 5.9, 6.9, and 4.2 m, respectively, compared to drilled depths of 9.1, 8.4, and 8.4 m, respectively, suggesting that fine gravel, sand, silt, and clay infilled the holes 3.0, 1.5, and 3.7 m, respectively. The holes are only 3 m apart, and the water levels measured on September 11, 1975, were 5.9, 4.7, and 3.3 m, respectively, below land surface. The water-table slope (0.42 m/m) is unrealistically high and reversed from the gradient depicted by the other wells. Therefore, it is believed that these water levels show effective hydraulic connection with the underlying gravel; wells 25 and 26 were at least cased into the gravel, whereas well 27 had sloughed in to a point 1.3 m above the top of the gravel before the casing was installed. Most of the fill within the casings is believed to be tailings materials.

The reason for questioning the validity of the water-table maps in representing water levels within the tailings is the effect of well construction upon the water levels. Variation in depth of gravel penetrated, extent of sloughing before casing installation, and the settling out of finer material within the casing will all affect the water-level response of the wells. The water quality data were used to aid in determining flow direction, once the leakage effects were considered.

The groundwater flow map (Figure 32, page 78), has two types of arrows. The open arrows show the effect of the pre-mining stream channel's ability to move groundwater from the hills that lie to the south and from the marginal area of the tailings. The high iron and sulfate values determined for well 6 during November and December 1974 and January 1975 (Appendix E) suggest either that some tailings-material groundwater is drained off during the winter or that the channel becomes nearly stagnant, and weathering reactions adjacent to the channel are affecting the water quality.

The dark arrows represent the flow pattern based upon the measured water levels and, to a lesser extent, upon the water chemistry. The high iron and sulfate values for samples from wells 8, 10, and 15 suggest that a low-permeability zone separates them from the main flow path (heavy arrows). The very slow rise of the water level in well 14, as well as the iron and sulfate concentrations, suggest a less permeable area. Well 14 is shallow, the bottom being only slightly more than 3 m below the original land surface. Consequently, it is believed to be the least affected by the influence of the underlying gravel. The observation that the water levels


COOKE CITY
x 7661
7650
x 7642
x 7637
x 7643
x 7637
35
29-Z
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7675
7675
7700
772
7750
Feet
0
100
200
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25
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75
100
Meters
N
CONTOUR ELEVATIONS ARE IN FEET M S L

FIGURE 32 Generalized flow map showing direction of groundwater movement within the tailings (July 2, 1975).

in well 14 are in reasonable agreement with the water tables constructed when omitting well 14 suggest that the flow directions inferred from the water table maps are correct in general form but would be altered locally by further monitoring of the wells drilled during the 1975 field season.

Mineral Stabilities. The water samples collected at the culvert weir spring (site 321), although believed to be the result of mixing, do provide some preliminary clues to the reactions affecting the water composition. First, the presence of secondary gypsum within the tailings should be expressed by saturation values for this mineral unless mixing is significant. The calculated ion activity product, $10^{-5.344}$, for the August 4, 1975, sample is considerably less than the ion activity product at equilibrium, which is $10^{-4,862}$. These data suggest that a minimum dilution of two parts distilled water with one part tailings water is necessary to account for the observed undersaturation. Samples collected on the same date from wells 3, 5, 10, and 14 were supersaturated with respect to gypsum and samples from wells 2, 6, and 16 were at 0.4, 0.1, and 17 percent saturation, respectively. These later samples are believed to represent the unaffected groundwater (well 2), a mixture of groundwater and surface water underflow (well 6), and the initial stages of influent surface water and groundwater reacting with tailings (well 16).

The chemistry of the spring water is very similar to that of the McLaren adit discharge. The major difference between them is the extent to which sulfide weathering and other reactions proceed during the contact of the water with the tailings. Oxygen may be consumed according to Stumm and Morgan's (1970, pp. 540.542) pyrite oxidation model (stoichiometrically or roughly so, using equations (4) and (7), Appendix D), but the field and laboratory data for the August 4, 1975, sample (pH = 6.46, Eh = 197 mv, total dissolved iron = 106 mg/l, sulfate = 556 mg/l, HCO_3^- (at lab pH of 5.50) = 106 mg/l, computer calculated ionic strength = 0.0198) suggest that the iron levels are controlled by the formation of amorphous $Fe(OH)_3$. Using these iron and sulfate concentrations, a value of 66.9 percent may be calculated using equation (12), Appendix D, for the iron released by pyrite weathering which actually reaches the spring. The water composition suggests that roughly one-third of the iron released by sulfide weathering is precipitated in the tailings; this is in general agreement with field and laboratory examination of the drill core and cuttings.

A list of the minerals calculated to be supersaturated, based upon the composition of the tailings effluent at the spring, includes:

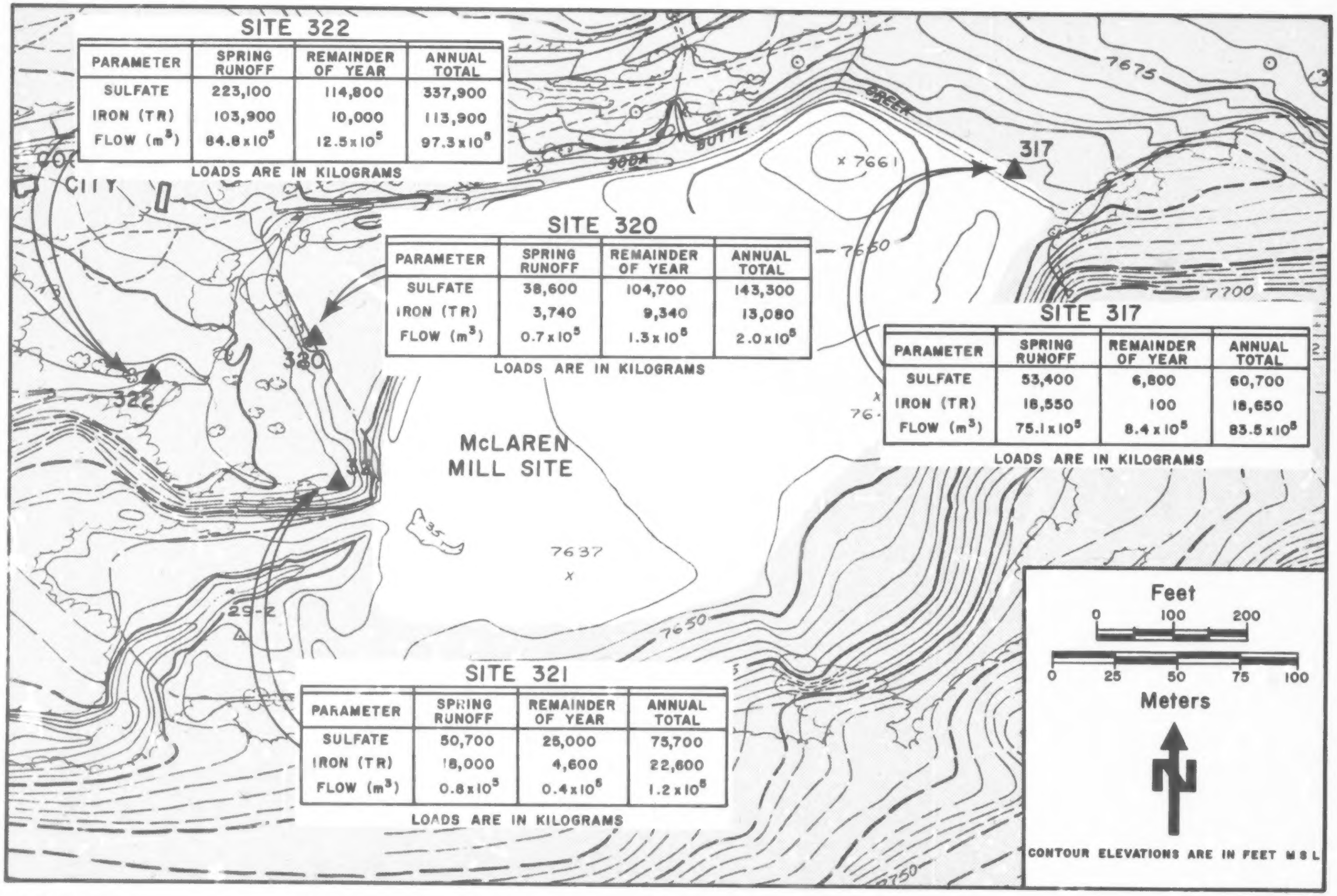
adularia
alunite
bixbyite
boehmite
cristobalite
diaspore
$Fe(OH)_3$amorphous
gibbsite
goethite
halloysite
hematite
illite
jarosite
kaolinite
K-mica
laumontite
leonhardite
maghemite
magnetite
$Mn(OH)_3$
montmorillonite
pyrolusite
pyrophyllite
quartz

This list contains many minerals not identified optically or by x-ray diffraction. Some of the missing species may be present in trace amounts as coatings, others may not have formed for kinetic reasons, and a few may not actually be as stable as calculated, owing to poor thermodynamic data. Lastly, although the solution may be saturated with respect to several solid phases, some of these minerals will be unstable with respect to others (the simplest example is SiO_2, where the solution is saturated with respect to quartz and cristobalite and nearly saturated (84%) with respect to chalcedony). If equilibrium were attained, the number of phases would be constrained by the phase rule, but because of seasonal fluctuations of the water table and of groundwater velocities and therefore of the fugacity of oxygen, it is doubted that equilibrium is ever attained, even within a small volume of the tailings.

Annual Flow and Metal Loads. An analysis of the annual flow and total metal load at various water quality sampling sites at the McLaren mill site will help to illustrate the sources and amount of pollutant load. Four sites, 317, 320, 321, and 322, have been chosen to show the metal load at each site. The annual load was determined for water year 1975, and the method for determining the load has been described previously on page 41.

Figure 33, page 81, shows the metal load for the McLaren mill site for sites 317, 320, 321, and 322. The load has been determined for the spring runoff period (May 15, 1975 to August 5, 1975), the remainder of the water year (October 1, 1975 to May 15, 1975 and August 5, 1975 to September 30, 1975), and the total 1975 water year.

The determination of pollutant load at each source now, and after any reclamation, will help to determine the effectiveness of the reclamation.


CITY
SODA
BUTTE
CREEK
317
320
321
322
29-2
7675
7661
7650
7700
7637
7750
McLAREN
MILL SITE
Feet
0
100
200
0
25
50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET M S L

SITE 322

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
SULFATE	223,100	114,800	337,900
IRON (TR)	103,900	10,000	113,900
FLOW (m^3)	84.8×10^5	12.5×10^5	97.3×10^5

LOADS ARE IN KILOGRAMS

SITE 320

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
SULFATE	38,600	104,700	143,300
IRON (TR)	3,740	9,340	13,080
FLOW (m^3)	0.7×10^5	1.3×10^5	2.0×10^5

LOADS ARE IN KILOGRAMS

SITE 317

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
SULFATE	53,400	6,800	60,700
IRON (TR)	18,550	100	18,650
FLOW (m^3)	75.1×10^5	8.4×10^5	83.5×10^5

LOADS ARE IN KILOGRAMS

SITE 321

PARAMETER	SPRING RUNOFF	REMAINDER OF YEAR	ANNUAL TOTAL
SULFATE	50,700	25,000	75,700
IRON (TR)	18,000	4,600	22,600
FLOW (m^3)	0.8×10^5	0.4×10^5	1.2×10^5

LOADS ARE IN KILOGRAMS

FIGURE 33 Metal loads at McLaren mill site for water year 1975.

SECTION 5

BIOLOGICAL STUDY

Introduction

During the summer of 1975, the Montana Department of Fish and Game conducted a biological study on three acid mine impacted streams near Cooke City, Montana. The purpose of the biological portion of the study was to supply input into the selection of a technique or techniques to reduce and treat the acid mine seepage, originating at three abandoned hard rock mine sites Specifically, this portion of the study was designed: (1) to determine the existing degraded conditions of the biological communities in the three impacted streams below the acid mine sites, and (2) to attempt to define what components of the wastes are responsible for this degradation. This information could then be used to estimate how effective, e.g., percent removal of heavy metals, etc., any abatement technique must be to restore a viable fishery to the streams.

The field portion of the study was conducted from May 19 through September 30, 1975. In this report, reference is made to fourteen sampling stations. The stations were sampled for water quality and/or biological data on a monthly or bimonthly schedule, depending upon need and accessibility. The biological study sampling stations and their EPA site numbers are shown on Figure 34, page 83.

Chemical Sampling

Basic Chemical Parameters and Heavy Metal Analyses

Water samples for laboratory analyses were periodically collected in polyethylene bottles at all stations. Four sample bottles were collected at each station, as follows: (1) one 1,000 ml bottle, filtered (in the field) through a 0.45 micron filter, (2) one 1,000 ml bottle, unfiltered ("as is"), (3) one 1,000 ml bottle unfiltered, but acidified with 10 ml of concentrated nitric acid (HNO_3), and (4) one 250 ml bottle filtered through the 0.45 micron filter and acidified with 2.5 ml of concentrated nitric acid. The bottles were refrigerated to 4°C and sent to the laboratory where they were analyzed for the following constituents:

1. Basic parameters - bicarbonate, calcium, carbonate, chloride, hardness, magnesium, manganese, nitrate, pH, potassium, silica, sodium, specific conductance, sulfate, and total alkalinity.

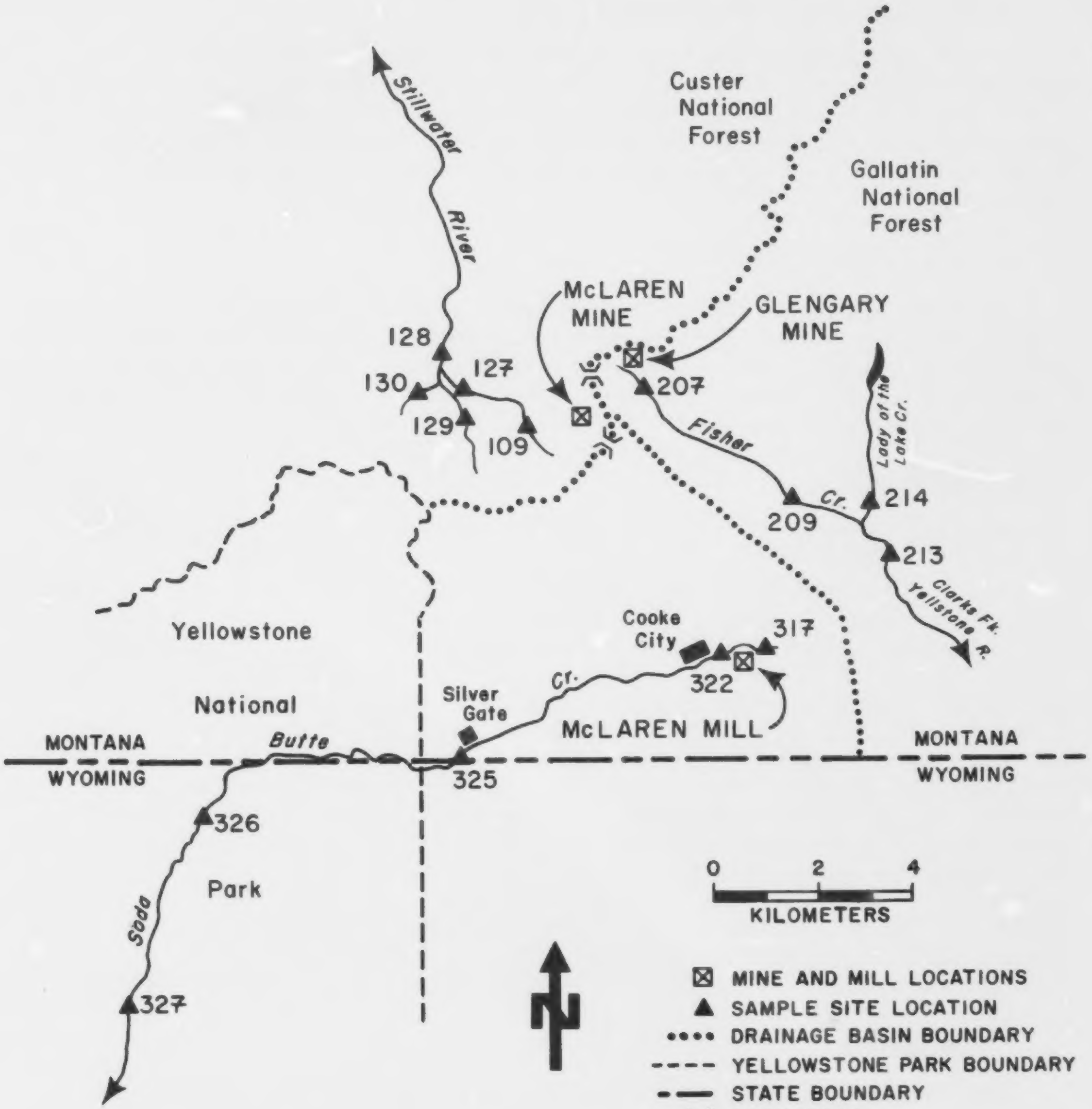

Stillwater River
Custer National Forest
Gallatin National Forest
McLAREN MINE
GLENGARY MINE
128
130
127
129
109
207
Fisher Cr.
Lady of the Lake Cr.
209
214
213
Clarks Fk. Yellowstone R.
Yellowstone National Park
Cooke City
317
322
Silver Gate
Cr.
McLAREN MILL
MONTANA
WYOMING
Butte
325
MONTANA
WYOMING
326
Soda
327
0
2
4
KILOMETERS
⊠ MINE AND MILL LOCATIONS
▲ SAMPLE SITE LOCATION
•••• DRAINAGE BASIN BOUNDARY
---- YELLOWSTONE PARK BOUNDARY
–·– STATE BOUNDARY
TRAIL PASS
■ TOWN

FIGURE 34 Location of water quality and biological sampling stations.

2. Heavy metals (dissolved and total) - aluminum, cadmium, copper, iron, lead, and zinc.

Field Physiochemical Determinations

Field measurements for dissolved oxygen, specific conductance, and temperature were also made concurrently with the water sampling. Dissolved oxygen was measured with a YSI model 57 meter. Specific conductance was determined with a YSI model 33 Salinity-Conductivity-Temperature meter. Stream temperatures were also made with this meter or with a hand-held field thermometer.

Stream Sediment Analyses

In late September, stream bottom gravels were collected at nine of the sampling stations. The gravels were returned to the laboratory, where they were dried, and filtered through a 0.074 mm sieve. Heavy metal determinations for aluminum, cadmium, copper, iron, lead, and zinc were then made on this fraction of the sample.

Biological Studies

Benthic Insects

Aquatic larval insects were collected from the bottom gravels by using a Surber Sampler. A sample of creek bottom (.09 m^2) was taken at each station on each water chemistry collection date. The insects were preserved in the field with 70 percent ethyl alcohol and returned to the laboratory, where they were enumerated and separated into basic taxonomic groups (Orders). In this report the orders of mayflies (Ephemeroptera), stone flies (Plecoptera) and caddis flies (Tricoptera) are considered to be "sensitive" to changes in water quality, while the rest of the orders (true flies, beetles, etc.) are considered to be "tolerant" to such changes. This admittedly is a fairly general categorization; but it is widely used, particularly when the time or taxonomic keys for an area are not available for further identification. A healthy stream section would therefore contain a large number of insects, with a high percentage being pollution "sensitive". Any reduction in total numbers or in the percentage of sensitive organisms from a control station would indicate stream degradation.

Fish Shocking

The presence or absence of fish was determined at each station by shocking a 23 to 90 m stream segment. A small, battery-operated backpack fish shocker, capable of producing up to 425 volts, was used. While this is a fairly reliable method for attracting fish, other factors such as the electrical conductivity of the water, or simply the lack of suitable physical habitat may bias the information.

Bioassays

A bioassay is an evaluation of the toxicity of a pollutant in which living organisms (in this case fish) provide the scale. Fish are exposed to a waste, or a diluted fraction of a waste, and their ability to survive is noted. All fish used in this study were small (3-6 cm) Yellowstone cutthroat trout (Salmo clarki). The fish were transported from the Montana Department of Fish and Game Yellowstone River trout hatchery at Big Timber, Montana, to Cooke City, where they were acclimated for at least 15 days in flow-through aquaria. Miller Creek, which provides the drinking water for some residents of Cooke City, was used for this acclimation.

In-Situ (Caged Fish) Bioassays. For this portion of the bioassays, ten fish were placed in 50 x 30 x 30 cm fiberglass mesh bags, supported by metal frames. The tests were conducted for a 72-hour period at six stations, and for two 96-hour periods at three stations.

Flow-Through (Aquaria) Bioassays. A small camper trailer, equipped with eight 38-liter aquaria and eight liquid proportional metering pumps (Matheson Scientific No. 56542), was used for this portion of the bioassays. The bioassay unit was located at station 322, which is below the McLaren mill tailings, near Miller Creek. This system automatically combined acid mine water from Soda Butte Creek with dilution water from Miller Creek into present proportions. The following proportions of Soda Butte Creek water were used: 100, 69, 47, 32, 22, 15, 10, and 9 percent. The pumps were set to deliver 200 ml of the above proportions per minute. Standpipe drains maintained a volume of 30 liters in each aquarium, which allowed the test solutions to be turned over approximately ten times per day. Water quality samples taken from the aquaria indicated that the pumps maintained the above dilutions within ± 2.0 percent. Two flow-through bioassays were conducted for 96 hours per test.

Fish Tissue Analyses. Fish from all bioassays were removed at the end of four days, frozen, and taken to the laboratory for heavy metal analyses. Since the fish were so small, several from each site were pooled prior to analysis. The fish were also skinned, which allowed each sample to be divided into two subsamples: (1) tissue and bones, and (2) heads, internal organs, and skin.

Results

Because individual abatement techniques will have to be applied at each of the three impacted areas, the results of the biological study will be presented in three different sections, i.e., Stillwater, Clarks Fork, and Soda Butte drainages.

Stillwater - McLaren Mine Area

Chemical Sampling

Basic Chemical Parameters. Water chemistry and biological samples were collected in the headwater area of the Stillwater River on August 5 and 20, and September 5 and 15, 1975. This area was not accessible by four-wheel vehicles before early August, which was unfortunate, since the peak runoff from the McLaren mine area was in mid-July. The six-week sampling period therefore spanned the stream stages of high-flow recession and low-flow, high temperature.

With the exception of two parameters, the concentrations of the basic chemical constituents increased with time (decreasing flow), and decreased with distance downstream from the mine. As was expected, total alkalinity and pH did not conform to this pattern. Total alkalinity clearly increased both with time and with distance from the mine. The pH values demonstrated a similar, yet less precisely delineated pattern. Water quality data for the Daisy Creek-Stillwater stations 109, 127, 128,and 129 are presented in Appendix E.

Heavy Metals. Of the three impacted areas which were studied for this report, the stream below the McLaren mine (Daisy Creek) consistently contained the highest concentrations of heavy metals. At station 109, the dissolved values for copper, iron, and particularly aluminum, were always much higher than concentrations reported in the literature to be toxic to trout (greater than 2.0 mg/l). The dissolved concentrations of the other three metals--cadmium, lead, and zinc--were much lower, with only zinc appearing at values greater than 0.01 mg/l. By station 127, 3 km below the mine, these concentrations were reduced, without any consistent pattern, to values 2 to 100 times less than those found at station 109. Below station 127 and before station 128, the other two feeder streams of the Stillwater converge with Daisy Creek to form the headwaters of the river. In this 0.5 km section of the stream, most of the heavy metals are rapidly precipitated, and by station 128, no dissolved concentrations were ever found at values above 0.1 mg/l (Appendix E). This removal of dissolved metals is no doubt prompted by the relatively high buffering capacity of the middle and west feeder streams, which have never been influenced by mining activity. The only water sample collected from the middle feeder stream contained a total alkalinity concentration of 87 mg/l, nearly 20 times the highest concentration found at station 127. Also, throughout the study period, the flow of both the middle and west feeder streams was roughly equal to Daisy Creek, which added a considerable amount of alkaline dilution to the upper river system.

Stream Sediment Analyses. The results of the heavy metal determinations for the fine (0.074 mm sieve) gravels from the Stillwater drainage are presented in Table 10,p. 87. Significantly higher concentrations of precipitated metals were found at station 128 compared to the control station (129), or to the station above the confluence of the other two feeder streams (station 127). Two exceptions were iron and lead, which were slightly more concentrated at station 127 than at station 128.

Biological Studies

Benthic Insects. The total number of benthic insects was severely reduced at station 127, with only two insects being found on four sampling dates, for an average of 0.5 organisms per 0.09 m^2. At station 128, the number of benthics had not recovered nearly as dramatically as the improve-

TABLE 10. HEAVY METAL ANALYSES OF STREAM GRAVELS, STILLWATER DRAINAGE, (INμg/g).

Station	Aluminum	Cadmium	Copper	Iron	Lead	Zinc
127	77,140	2.2	2,640	93,300	173	260
128	87,490	7.6	11,450	84,450	116	1,280
129	73,190	1.5	83	40,250	66	129

ment in water quality might hint, since the average number had only increased to 3.75 organisms per 0.09 m^2. These values are very low compared to the control station (129), which contained an average value of 118 organisms per 0.09 m^2. Station 129 had a clean, fine gravel bottom, while the former two stations had a "cemented", heavy metal appearance. Due to low benthic population at station 127, no bottom samples were collected at the even more degraded area of station 109.

Fish Shocking. On September 17, 1975, stream segments ranging from 30 to 90 m were shocked in the vicinity of stations 127, 128, and 129. No fish were found. In addition to checking these normal sampling sites for the presence of fish, several more pool and riffle areas were shocked on the mainstem of the Stillwater as far as 1.3 km below station 128. No fish were found even in stream sections with excellent physical habitat. The electrical conductivity of the water was apparently conducive to shocking, since numerous insects were stunned and floated to the surface in the vicinity of the control site.

Bioassays. One 72-hour in-situ bioassay was conducted from September 15 through September 18, 1975. Cages were placed at stations 127, 128, and 129. At station 127, all ten fish were dead after 24 hours. At station 128, only two fish died after 72 hours, yielding a survival of 80 percent; the surviving fish were quite healthy and responsive, showing little abnormal behavior or stress. All of the control fish at station 129 survived the test.

Heavy Metal Analyses of Fish Tissue. The concentrations of aluminum and copper in the head, skin, and internal organs (composite) subsample of fish from station 127 were much higher than the values for these metals at any of the other stations in the study. These concentrations indicate that the cause of fish mortality in the bioassay at station 127 was very likely due to these two metals. The results of fish tissue analyses for the Stillwater stations are presented in Table 11, page 38.

Clarks Fork - Glengary Mine Area

Chemical Sampling

Basic Chemical Parameters. Four stations were sampled in the headwater

TABLE 11. HEAVY METAL CONCENTRATIONS IN FISH FLESH FROM THE STILLWATER/ McLAREN MINE STATIONS SEPTEMBER 1975 (IN μg/g DRY WEIGHT).

Head, skin, and internal organs composite

Station	Aluminum	Cadmium	Copper	Iron	Zinc
127	780	1.05	279	803	113
128	260	1.34	153	254	249
129	69	1.22	9	119	95

Flesh and bones composite

Station	Aluminum	Cadmium	Copper	Iron	Zinc
127	54	< .60	335	86	68
128	37	< .60	151	254	82
129	21	< .60	6	54	75

area of the Clarks Fork Yellowstone from August 5 through September 23, 1975. As was true of the Stillwater drainage, the high stream runoff period (early July) was not sampled. The four sampling dates (August 5, 20, and September 5 and 23, 1975) were therefore all within the low-flow, high-temperature stream stage.

With two exceptions, total alkalinity and pH, the concentrations of the basic chemical parameters increased: (1) with decreasing flow, and (2) with increasing distance from the mine site. Both total alkalinity and pH increased at the sampling stations downstream from the mine, but slowly decreased as the flow, in turn, began to subside. Water quality data is presented in Appendix E. It should be noted, however, that these latter two parameters demonstrated a rather sporadic response to changes in flow, a reflection of the poor buffering capacity of streams in the Upper Clarks Fork drainage.

Heavy Metals. Even at the furthest upstream station (207) the heavy metal concentrations were far lower than those found in the upper stations of the Stillwater - McLaren mine area. At station 207, aluminum and copper were the most concentrated dissolved metals, the former being found in the 1.9 to 2.7 mg/l range, and the latter in the 0.7 to 0.8 mg/l range. Dissolved iron was never found above 0.3 mg/l, and zinc was always less than 0.2 mg/l. The dissolved cadmium and lead concentrations were always less than 0.01 mg/l. At site 209, 4 km below the mine, and at site 213, below the confluence of Lady of the Lake Creek, no dissolved heavy metal ever exceeded 0.1 mg/l. These data are presented in Appendix E.

Stream Sediment Analyses. Stream gravels were collected at stations 209, 213, and 214. The results of the fine (0.074 mm sieve) gravels are in Table 12,p. 89. In the stream sediment analyses, no distinct patterns of heavy metal

TABLE 12. HEAVY METAL ANALYSES OF STREAM GRAVELS, CLARKS FORK DRAINAGE, INμg/g.

Station	Aluminum	Cadmium	Copper	Iron	Lead	Zinc
209	80,690	2.5	3,130	73,650	153	320
213	68,800	3.5	2,070	67,750	133	400
214	72,530	3.8	2,300	62,850	163	460

precipitation were evident. In fact, three metals, cadmium, lead, and zinc, were more concentrated in the sediments of the control station than at either of the affected stations.

Biological Studies

Benthic Insects. An improvement in total number of benthic insects can be seen with distance downstream from the mine. At station 209, an average of 5.25 organisms per 0.09 m^2 were collected, and by station 213, this average had increased to 9.75. These values were lower than the control station (214), where 12.0 organisms per 0.09 m^2 were collected.

Fish Shocking. On September 18, 1975, three 100 m stream segments were shocked in the vicinity of stations 209, 213, and 214. No fish were found at any of these stations. Although the physical habitat at all stations appeared suitable to support fish, the electrical conductivity of the water was quite low, greatly lowering the efficiency of the shocking unit. Fish may have been present but possibly were not attracted to the unit's probes.

Bioassays. One 72-hour in-situ bioassay was conducted from September 16 through September 19, 1975. Fish cages were placed at stations 209, 213, and 214. No mortalities occurred at any of the stations. However, the test at station 209 was terminated at 60 hours by vandals removing the cage from the stream.

Heavy Metal Analyses of Fish Tissue. In this drainage, the metal concentrations contained in the bioassay fish were far lower than the values found in fish from the other two study areas. This should be expected, since no fish mortalities were recorded at any of the Clarks Fork stations. The fish tissue analyses for this drainage are presented in Table 13, page 90.

Soda Butte - McLaren Mill Area

Chemical Sampling

Basic Chemical Parameters. Water samples for complete analyses were collected on eight dates from May 19 through September 14, 1975. The mill tailings had a moderate influence on the basic water chemistry of Soda Butte Creek. In fact, the concentration of major cations increased slightly at

TABLE 13. HEAVY METAL CONCENTRATIONS IN FISH FLESH FROM THE CLARKS FORK-GLENGARY MINE STATIONS, SEPTEMBER 1975 (IN μg/g DRY WEIGHT).

Head, skin, and internal organs composite

Station	Aluminum	Cadmium	Copper	Iron	Zinc
209	325	$<$ .60	37	346	120
213	78	.60	8	67	108
214	81	.68	11	240	125

Flesh and bones composite

Station	Aluminum	Cadmium	Copper	Iron	Zinc
209	27	$<$ .60	7	52	79
213	24	$<$ .60	5	67	75
214	19	$<$ .60	8	60	76

station 322 over the values recorded at station 317. These values decreased rather sharply at station 325, due to the influence of Woody Creek, which enters Soda Butte Creek 4 km above station 325. Although this tributary was not sampled extensively, one sample taken near its mouth on June 17, 1975, revealed that it is a typical softwater mountain stream, with major cation and anion concentrations two to four times lower than those found at site 322. The flow of Woody Creek throughout the sampling period was roughly equal to the flow of Soda Butte Creek at their confluence. Below station 325, water samples taken at stations 326 and 327 demonstrated that the concentrations of the major cations gradually increased. This information is illustrated in Figure 35, page 91, using calcium and magnesium as typical major cations.

The major anions demonstrated slightly different concentration patterns from those of the cations. As expected, the sulfate concentration jumped sharply at station 322, and then decreased sharply by station 325, after which it continued to decrease slowly at the downstream stations. One notable exception to this pattern was on July 2, 1975,during the peak runoff, when the sulfate concentration at station 317 was much higher than at all other stations. This information is present in Figure 36, page 92. The concentration pattern for total alkalinity (the sum of the carbonate, bicarbonate and hydroxide components) was very similar to that of the major cations with one obvious exception; a reduction in concentration, rather than an increase, occurred below the tailings. This again was expected, but the amount of reduction was less than what normally occurs below most acid-mine wastes. A notable exception to this pattern was during the early July runoff (Figure 37, page 93).

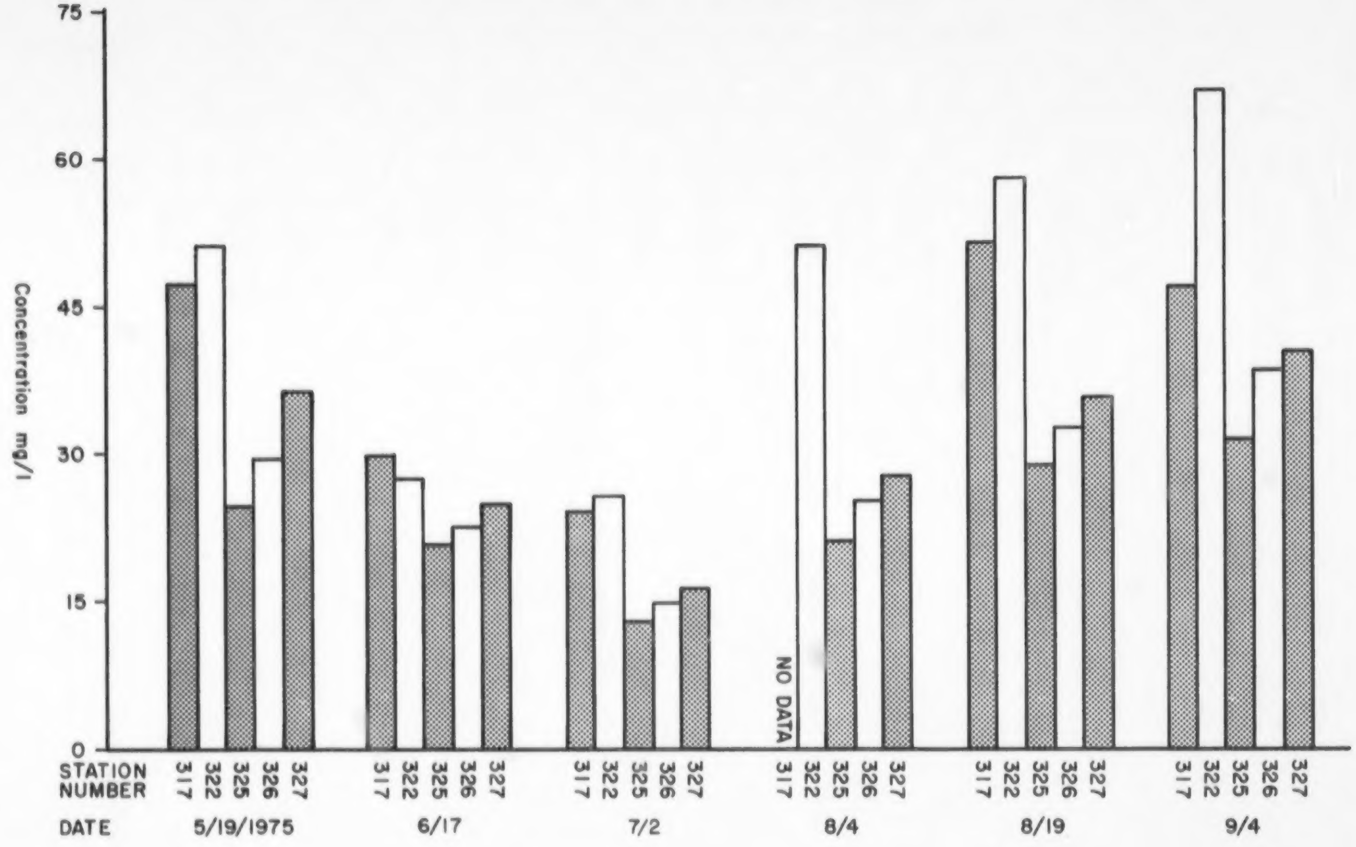


FIGURE 35 Variations in calcium plus magnesium at each station during the study period-Soda Butte Creek.

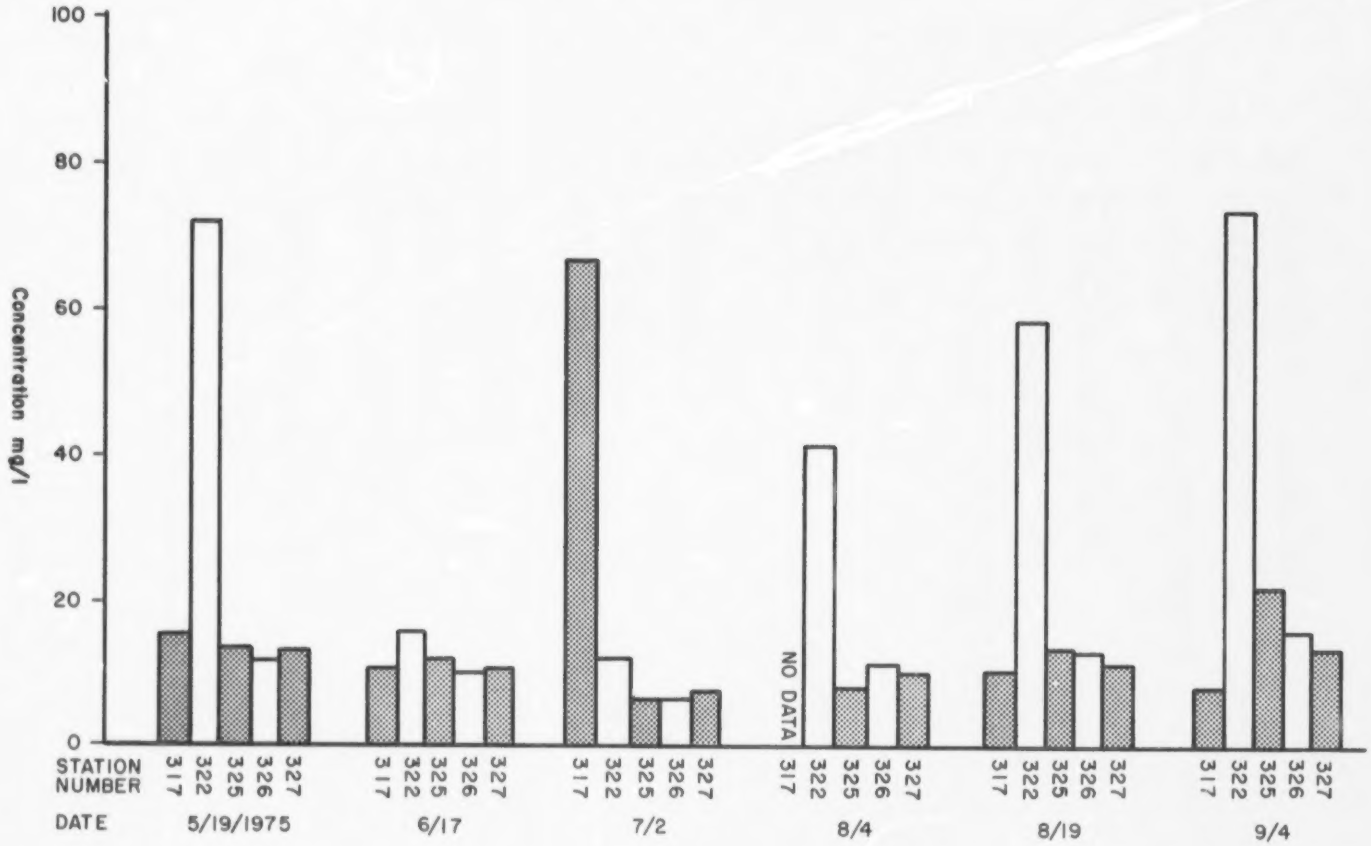


FIGURE 36

Variations in sulfate at each station during the study period – Soda Butte Creek.

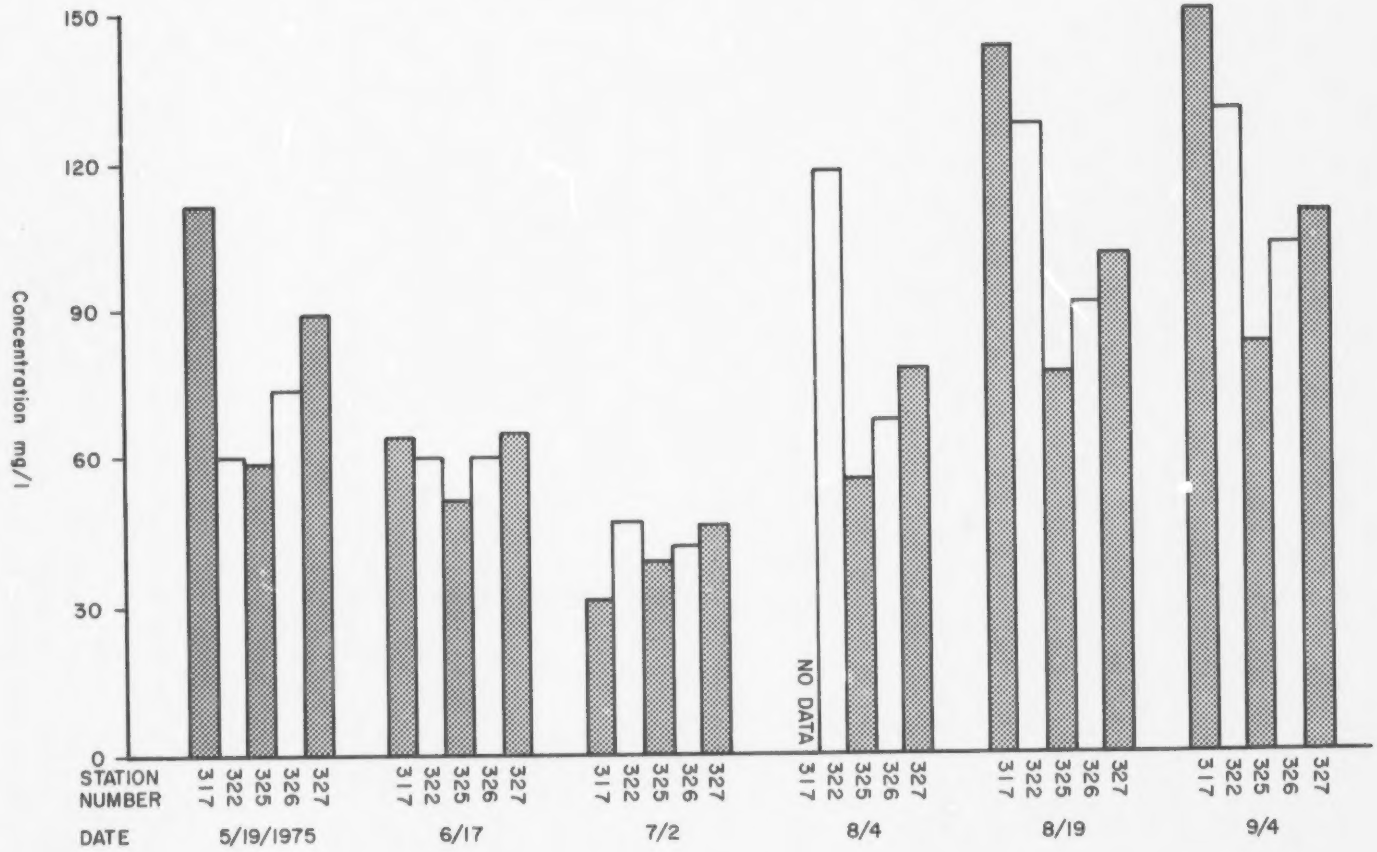


FIGURE 37 Variations in total alkalinity at each station during the study period–Soda Butte Creek.

Heavy Metals. Throughout the study period, at all sampling stations, iron was by far the dominant heavy metal. Even at station 322, which is immediately below the mill tailings, the dissolved concentrations of aluminum, cadmium, copper, lead, and zinc exceeded 0.1 mg/l on only one occasion; this was during the early July runoff, when the concentration of dissolved aluminum was 4.55 mg/l and the concentration of dissolved copper was 0.50 mg/l. At stations 325, 325, and 327, the concentrations of these five metals was even less, never exceeding 0.02 mg/l. Quite in contrast to the other metals was the dissolved iron concentration, which was often several orders of magnitude more concentrated than the other five metals. Most significantly, at station 322, dissolved iron concentrations were as high as 11.60 mg/l, with values often occurring within the 3.0 to 6.0 mg/l range. Not surprisingly, there was a very significant decrease in dissolved iron at stations 325, 326, and 327, with the concentration exceeding 0.1 mg/l on only two occasions. In late summer, iron concentrations at these downstream stations were always less than 0.02 mg/l (Figures 38 and 39, page 95).

Stream Sediment Analyses. The results of the heavy metal determinations for the fine (0.074 mm sieve) gravels from Soda Butte Creek are presented in Table 14.

TABLE 14. HEAVY METAL ANALYSES OF STREAM GRAVELS, SODA BUTTE CREEK (INμg/g).

Station	Aluminum	Cadmium	Copper	Iron	Lead	Zinc
322	63,780	2.6	1,060	134,600	141	249
325	79,270	2.4	165	68,750	74	174
326	79,120	1.8	128	75,600	64	139

The highest concentrations of precipitated metals were generally found at station 322, with lower concentrations being found further below the tailings. This decrease in concentration is nearly proportional to the distance from the tailings. Exceptions were with aluminum, which was more concentrated at the downstream stations, and iron, which was more concentrated at station 326 than at station 325.

Biological Studies

Benthic Insects. The total number of benthic insects was severely reduced immediately below the tailings at station 322; the percent of sensitive orders was also lower than at the control station (317). By station 325, the total number of benthics had nearly recovered, although the percentage of sensitive orders was still low. Inside Yellowstone Park at stations 326 and 327, the benthic insect community had completely recovered, both in the total and percent sensitive values. These data are summarized in Table 15, page 96.

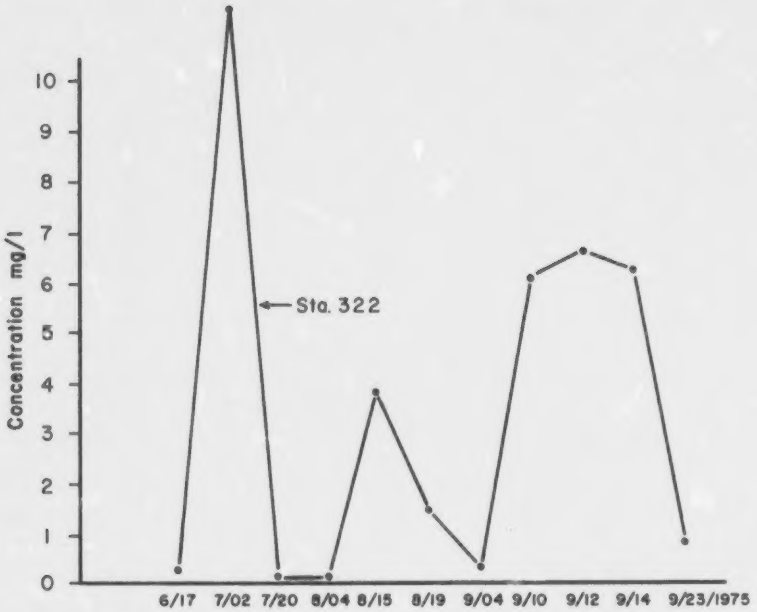


FIGURE 38 Dissolved iron concentrations, Soda Butte Creek, showing the frequent peaks at Station 322, which did not occur at the downstream stations.

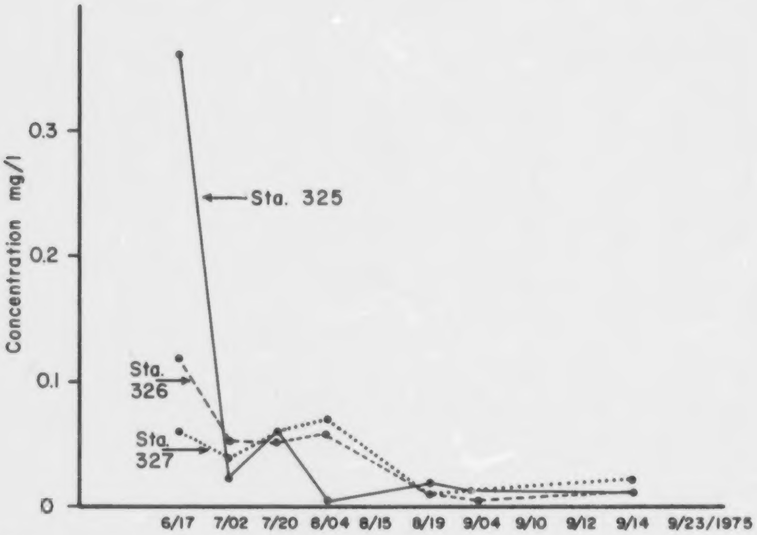


FIGURE 39 Dissolved iron concentrations at downstream stations.

TABLE 15. TOTAL AND AVERAGE NUMBER OF BENTHIC INSECTS COLLECTED (per 0.09 m^2) IN SODA BUTTE CREEK.

Date	Ple	Tri	Epe	Dip	Oth	Tot	%Sen	Ple	Tri	Epe	Dip	Oth	Tot	%Sen
	Station 317							Station 326						
5/19	11	20	25	8	0	64	88	17	4	37	6	0	64	91
6/17	0	0	2	0	0	2	100	0	4	3	4	0	11	64
7/15	0	0	7	1	0	8	88	1	0	10	0	0	11	100
8/04	14	0	19	3	5	41	80	0	2	14	1	0	17	94
8/19	24	1	12	6	3	46	80	4	3	24	2	4	37	84
9/04	4	0	15	7	2	28	68	3	2	18	0	0	23	100
9/14	45	4	20	12	1	82	84	2	4	31	1	2	40	93
TOT.	90	25	100	37	11	271		27	19	137	14	6	203	
	14.0	3.6	14.3	5.3	1.6	38.7	82	3.9	2.7	19.6	2.0	0.9	29.0	90
	Station 322							Station 327						
5/19	0	1	2	0	0	3	100	4	6	27	10	0	47	79
6/17	0	0	1	0	0	1	100	0	15	8	7	1	31	74
7/15	0	0	1	1	0	2	50	-	--	--	--	-	--	---
8/04	0	0	0	0	0	0	---	0	0	1	0	0	1	100
8/19	1	0	2	3	0	6	50	26	3	41	4	1	75	93
9/04	0	0	0	1	0	1	0	5	1	14	2	0	22	91
9/14	0	0	1	1	0	2	50	6	6	41	1	1	55	96
TOT.	1	1	7	6	0	15		41	31	132	24	3	231	
	0.1	0.1	1.0	0.9	0.0	2.1	60	6.8	5.2	22.0	3.4	0.5	38.5	88
	Station 325													
5/19	2	3	18	0	2	25	92							
6/17	0	0	3	0	0	3	100							
7/15	0	2	3	0	0	5	100							
8/04	0	1	3	0	0	4	100							
8/19	2	2	10	1	0	15	93							
9/04	5	6	23	1	0	35	97							
9/14	10	10	27	81	0	128	37							
TOT.	19	24	87	83	2	215								
	2.7	3.4	12.4	11.9	0.3	30.7	60							

Ple = Plecoptera (stone flies)
Tri = Tricoptera (mayflies)
Epe = Ephemeroptera (caddis flies)
Dip = Diptera (common flies)
Oth = Other benthic insects
Tot = Total
% Sen = Percent of pollution sensitive (Ple, Tri, Epe) benthics in each sample.

Fish Shocking. On September 19, 1975, four stream segments ranging from 30 to 120 m were shocked in the vicinity of stations 317, 322, 325, and 326. The only station where fish were found was station 326; three Yellowstone cutthroat trout (Salmo clarki) were captured, measuring 11, 27, and 29 cm. Several other fish were stunned at this station but were not captured due to the high stream velocity. Also, park rangers indicated that sportsmen often catch fish in the area of station 326.

Bioassays. Two 96-hour in-situ (caged fish) and flow-through (aquaria) bioassays were conducted concurrently from August 12 through August 16 and again from September 11 through September 15, 1975. For the in-situ portion, cages were placed at stations 317 (control), 322, and 325. The flow-through concentrations ranged from 0 to 100 percent Soda Butte Creek water, as described in the methods section. In both the August and September tests, the only fish mortality was in the cage at station 322. In August, 100 percent of the fish died, and in September, 80 percent had died after the 96-hour period. One of the flow-through concentrations was also 100 percent Soda Butte Creek water, taken from the creek immediately beside the cage at station 322. This water was transported from the creek to the bioassay unit, a distance of 50 m, through a 13 mm (inside diameter) polyvinyl chloride (PVC) pipe, where a pump completely exchanged the water in the aquarium ten times per day. However, no mortality occurred in the aquarium and nearly complete mortality occurred in the creek proper. If we look at the comparative water quality data between the creek and aquarium (Table 16, page 98), a distinct difference exists in the dissolved iron concentrations. In the creek, this parameter ranged from 3.82 to 6.70 mg/l, while in the aquarium containing 100 percent Soda Butte Creek water it ranged from 0.30 to 0.66 mg/l, clearly an order of magnitude difference. No other water quality constituent, dissolved or total, reflected such an extreme difference. The dissolved iron apparently precipitated on all available surfaces, including the PVC line and glass aquarium, lowering its concentration to "safe" values (at least for an acute test) for the aquarium fish.

At station 322, during both the August and September tests, fish mortalities were recorded every twelve hours. At these time intervals, the total lengths of the dead fish were also measured to the nearest mm. These measurements, particularly during September when there was a wide variation in length between the test fish, demonstrated that the larger fish survived for longer periods in the highly concentrated dissolved iron water of station 322 (Figure 40, page 99).

Heavy Metal Analyses of Fish Tissue. The metal analyses of the head, skin, and internal organs (composite) subsamples for the Soda Butte stations demonstrated that the iron concentrations were at least seven times more concentrated in the fish from station 322 than at any of the other Soda Butte Creek stations (Table 17, page 100). Fish tissue analysis shows that the iron values in the fish tissue at this station were far above those found at any of the other stations. These data therefore support the water quality and bioassay information, both of which indicated that iron was the cause of mortality to the fish at station 322.

TABLE 16. COMPARATIVE WATER QUALITY DATA FROM STATION 322 (in-situ bioassay) AND 100% SODA BUTTE CREEK WATER (flow-through bioassay) (in mg/l).

Date	8/15		9/10		9/12		9/14	
		100%		100%		100%		100%
Aluminum - D	0.050	<0.050	<0.050	0.050	0.050	<0.050	0.050	<0.050
T	0.050	0.050	<0.050	0.050	0.050	0.050	0.050	0.050
Cadmium - D	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
T	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper - D	<0.001	0.002	0.004	<0.001	0.004	<0.001	0.004	<0.001
T	0.011	0.003	0.007	0.003	0.004	0.006	0.004	0.006
Iron - D	3.820	0.300	6.200	0.630	6.700	0.660	6.400	0.500
T	6.900	4.380	10.600	6.500	10.500	8.460	10.530	10.000
Lead - D	0.007	0.003	<0.002	<0.002	0.003	<0.002	<0.002	<0.002
T	0.009	0.003	0.010	0.003	0.004	0.008	0.009	0.004
Zinc - D	<0.001	<0.001	0.017	<0.001	0.018	<0.001	0.013	<0.001
T	0.004	<0.001	0.039	0.011	0.018	0.012	0.013	0.010
Calcium	45.000	45.980	52.000	46.400	52.000	51.740	51.500	51.580
Magnesium	9.900	10.300	13.400	11.000	13.200	13.020	13.500	12.530
Sodium	1.300	1.300	1.400	1.400	1.400	1.400	1.400	1.500
Potassium	1.000	1.100	1.400	1.200	1.300	1.400	1.300	1.300
Manganese	0.210	0.180	0.320	0.240	0.340	0.310	0.330	0.310
Bicarbonate	132.000	130.500	131.000	117.360	133.000	131.800	126.800	126.370
Sulfate	48.000	53.700	80.000	70.000	80.000	77.500	78.300	84.100
Conductivity - µmohs	305.700	311.900	271.700	332.700	372.900	367.400	370.500	362.800
pH	6.010	6.070	6.410	6.480	6.490	6.540	6.240	6.930
Dissolved Oxygen	7.100	6.700	7.300	5.900	6.900	6.800	9.300	7.200
Temperature -°C	9.000	10.500	10.000	15.000	7.000	11.000	7.000	7.000

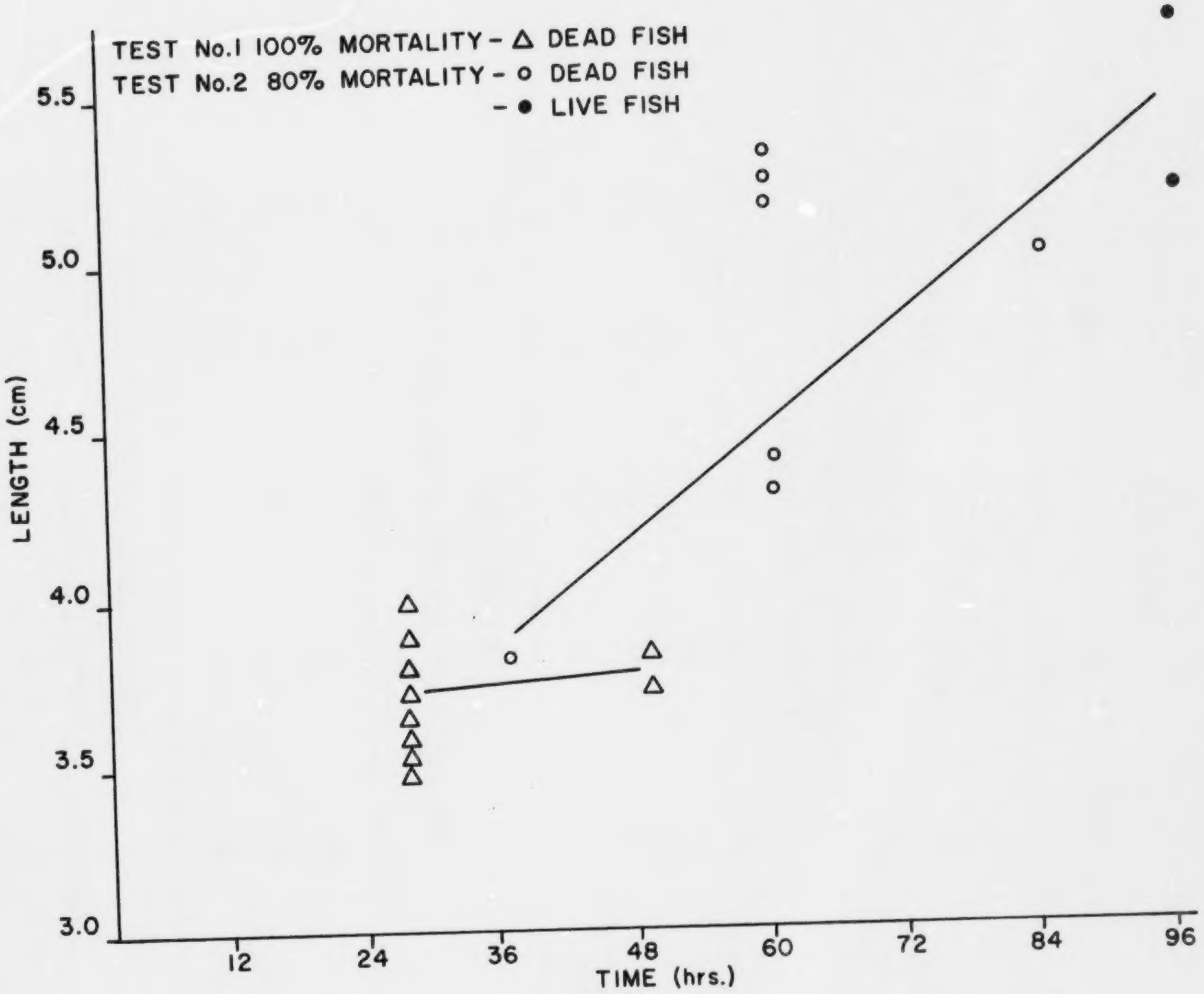


FIGURE 40 Length-mortality relationship in two, 96-hour in-situ bioassays at station 322, Soda Butte Creek.

TABLE 17. HEAVY METAL CONCENTRATIONS IN FISH FLESH FROM THE SODA BUTTE/ McLAREN MILL SITES (IN μg/g DRY WEIGHT).

August 1975

Head, skin, and internal organs composite

Station	Aluminum	Cadmium	Copper	Iron	Zinc
317	141	1.19	8	500	113
322	586	<.60	73	11,140	134
325	151	<.60	9	849	123
Bioassay tank-Soda Butte	59	<.60	10	585	115

Flesh and bones composite

Station	Aluminum	Cadmium	Copper	Iron	Zinc
317	31	<.60	8	168	101
322	64	<.60	17	460	110
325	5	<.60	10	153	103
Bioassay tank-Soda Butte	25	<.60	7	167	93

September 1975

Head, skin, and internal organs composite

Station	Aluminum	Cadmium	Copper	Iron	Zinc
317	85	2.57	7	728	110
322	52	.87	11	5,490	112
325	92	.60	8	632	127
Bioassay tank-Soda Butte	62	<.60	7	737	159

Flesh and bones composite

Station	Aluminum	Cadmium	Copper	Iron	Zinc
317	32	<.60	5	96	80
322	38	<.60	8	300	108
325	51	<.60	6	180	96
Bioassay tank-Soda Butte	27	<.60	5	90	113

Conclusions and Recommendations

Stillwater - McLaren Mine Area

It is fortunate that two relatively alkaline streams converge with Daisy Creek to form the Stillwater River. The buffering action of these two streams increases the pH and subsequently lowers the dissolved metal concentrations in the 0.5 km section of the Stillwater River immediately above station 128. At station 128, the pH of the stream is raised to a value that is almost acceptable for a biological community. However, the total metal load (originating at the McLaren mine) is still very high, even though the dissolved values are sharply reduced at this station. Because of the improvement in water quality at station 128, Yellowstone cutthroat trout are able to survive at this location for at least three days. Very little suitable physical habitat is available for benthic insects since the precipitated metals literally concrete the stream bottom. Without chronic bioassay data, which would be nearly impossible to obtain in this isolated area, using both insects and fish, it is difficult to say what the long-term effects of the metal concentrations at station 128 might be on these organisms.

If we look at reclamation only from a fisheries point of view, all efforts should be made to substantially reduce the aluminum, copper, and iron levels in the upper Stillwater River beginning at least 6 km below station 128. Based on the very slow recovery of benthic insects at station 128 and the unsuitable appearance of the bottom for some distance below this station, it would seem that a 90 percent reduction in the total load of these three metals would be in order.

It should be noted that a very steep stream gradient exists roughly 2.5 km below station 128. This presents a formidable physical barrier to the upstream migration of fish. This barrier, along with the deep snow pack, severe cold and low streamflows, occurring every winter in the vicinity of the sampling stations, has very likely prevented the existence of a native trout population in the upper 9 km section of the Stillwater. The furthest natural, upstream point for the native trout population in the river is probably near the confluence of Goose Creek, which enters the Stillwater roughly 6 km below station 128.

Clarks Fork - Glengary Mine Area

Heavy metals are much less of a problem in this area, compared to either the Stillwater or Soda Butte drainages. The pH and/or lack of alkalinity appears to be the major problem affecting the aquatic community. At station 209 the trout survived the bioassay without any noticable behavioral changes. The bottom substrate was quite untarnished, with the benthic population less drastically reduced over the control than was noted in the Stillwater stations (compared to their control station).

As was true of the Stillwater drainage, a rapid increase in stream gradient, roughly 1 km below station 209, presented a barrier to fish migration. If only the Clarks Fork proper is considered to ever have had a native trout population, then reclamation efforts should be directed towards increasing the pH of the Clarks Fork below Lady of the Lake Creek to near 7.0, a value which is characteristic of this tributary.

Soda Butte - McLaren Mill Area

The benthic insect in-situ bioassay and fish shocking data revealed that the biological community of Soda Butte Creek is significantly degraded only above station 325. Although no fish were collected at this station, it was quite noticeable that the streambed within the community of Silver Gate has been extensively altered. Most of the undercut banks, logs, and other physical habitat for fish have been removed. Area residents claim that fish are caught during certain times of the year above the town, but only in areas which have not been physically altered by man.

Soda Butte Creek is much more alkaline than either of the other two streams which were studied for this report. Even at station 322, the pH was consistently near 7.0. Iron was the most concentrated dissolved heavy metal. In the in-situ bioassays, a total of 90 percent of the test fish were killed in dissolved iron concentrations ranging from 2.0 to 6.0 mg/l. No fish mortality occurred in the flow-through bioassay, where the dissolved iron concentration ranged from 0.3 to 0.7 mg/l. A standard method for establishing safe concentrations of certain dissolved metals from bioassay data is to multiply the 96-hour median tolerance limit by 0.1. The median tolerance limit is that concentration at which 50 percent of the test organisms survive. Using the two extreme bioassay results, we can estimate that 50 percent of the fish would have survived at an average of the two test concentrations, roughly 2.0 mg/l. Multiplying this value by 0.1 we get 0.2 mg/l, the safe concentration for long-term exposure of juvenile cutthroat trout. Therefore, to significantly reduce the degraded conditions between station 322 and 325 and to enhance the biological community below station 325, the dissolved iron concentration at station 322 should not exceed 0.2 mg/l at anytime.

SECTION 6

RECLAMATION ALTERNATIVES

McLaren Mine Area

The sources of the pollutants at the McLaren mine site are: (1) runoff water during snowmelt and rainfall periods that flush acidity, heavy metals, etc., from the mine waste dump surface. These pollutants form as a result of weathering of pyritic materials, and (2) water that infiltrated into and percolated through the mine waste to resurface as seeps downgradient from the disturbed area. As the water passes through the mine waste, its concentration of heavy metals and acid significantly increases. Runoff water probably produces 70 to 80 percent of the annual pollution load. However, the highest concentration of acidity and metals occurs during low flow periods, a critical time for aquatic life, when almost all of the flow is from groundwater sources.

There are several solutions to the runoff problem: (1) reduce the amount of water crossing the mine waste by diverting all outside sources away and by reducing snow buildup on the mine site, (2) prevent contact between surface runoff and the mine waste by means of a barrier, and (3) prevent the weathering and erosion of the mine waste.

The diversion of water around the mine area would require a drainage ditch above the highwall (Figure 41, page 104). With a minimum amount of dozer work, one of the roads above the highwall could be used for this purpose. The seep at site 101 and any others at the base of the highwall should be diverted across the mine waste, discharging below the mine area into a lined channel. Thus, this water would not have an opportunity to infiltrate the mine waste or pick up pollutants as it passed across the waste. The ditch should be sealed with bentonite and lined with coarse gravel to prevent erosion.

To prevent the contact of surface water with the mine waste and to prevent further weathering and erosion of the mine waste, the waste should be covered with a soil-like material that does not contain pyrite and other acid- and heavy metal-producing materials. Since vegetation is very difficult to establish at the higher elevations and extreme environment of the mine site, an analysis was made of the material within the mine area to locate materials suitable as cover.

As noted in Table 18, page 105, samples were analyzed for pH and percent sulfur. Six different methods were used to determine lime requirements (LR) to neutralize the acid. The highest values for LR were obtained by the

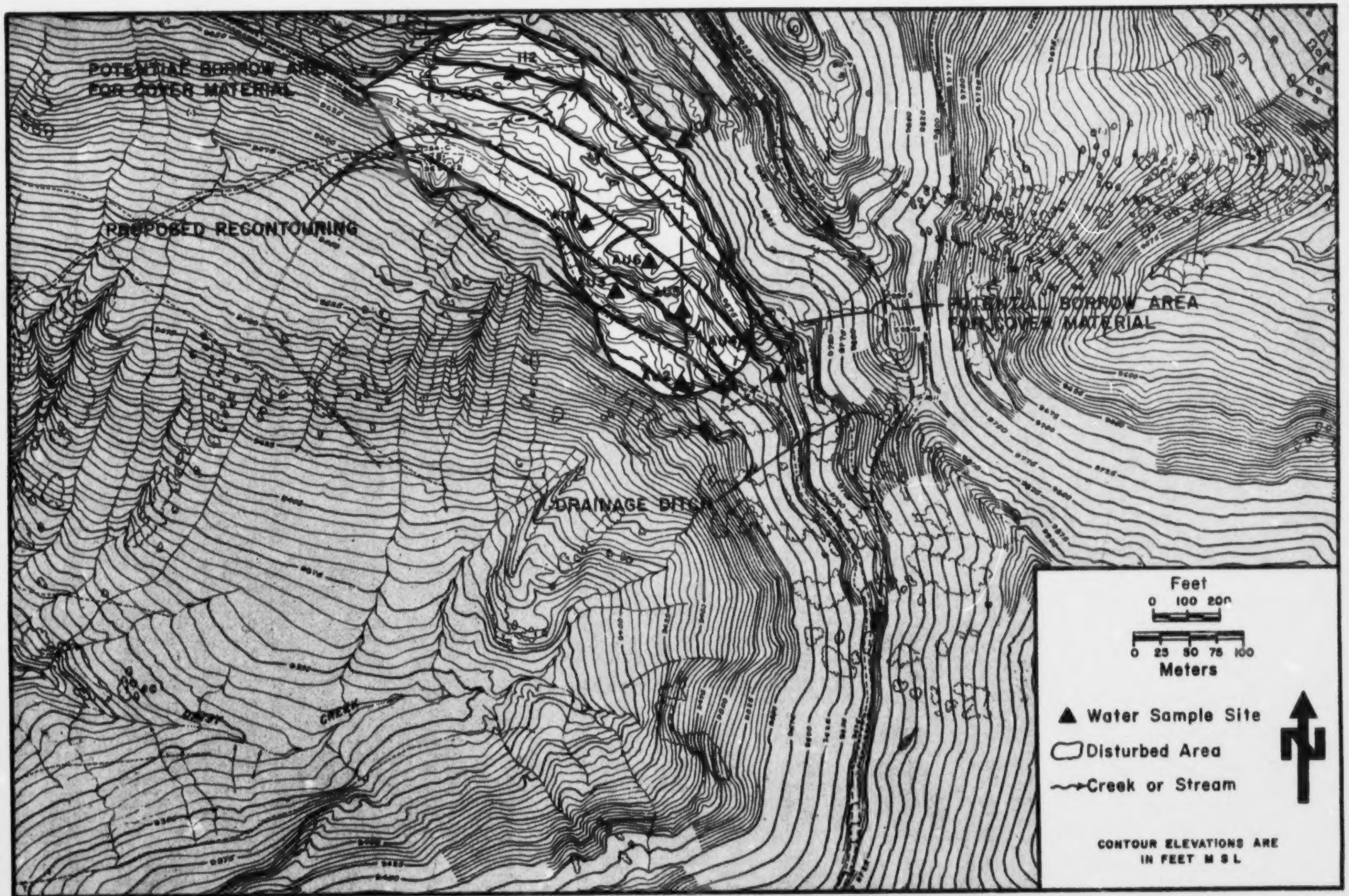

POTENTIAL BORROW AREA FOR COVER MATERIAL
PROPOSED RECONTOURING
POTENTIAL BORROW AREA FOR COVER MATERIAL
DRAINAGE DITCH
CREEK
Feet
0 100 200
0 25 50 75 100
Meters
▲ Water Sample Site
Disturbed Area
Creek or Stream
N
CONTOUR ELEVATIONS ARE IN FEET M S L

FIGURE 41 Proposed McLaren mine reclamation plan.

percent sulfur method. This method assumes that the sulfur, probably as pyrite, will be oxidized to produce acid. This value is the more conservative. The neutralization potential measures the readily available acid, as would the four-day incubation method. Further research is needed to determine the best method.

The results of the analysis show that the samples of mine waste (AU-1, AU-2, AU-3, AU-4, and AU-5) had low pH's, high levels of sulfur, and large lime requirements for soil neutralization. Only the 0-3 m samples at AU-3 had favorable properties. In general, all of this material should be buried with approximately 0.3 m of good material. It appears that cover

TABLE 18. CHARACTERISTICS OF MINE WASTE MATERIALS AT McLAREN MINE SITE

			Lime requirements Metric tons per hectare					
Site[a] no.	Depth (m)	pH	From[b] % S	Neut.[c] poten.	Woodruff[d]	SMP[e]	5-min[f] incub.	4-day[g] incub.
AU1	0-1.3	2.4	28	3.8	2.9	9.2	5.5	--[h]
AU1	1.3-4.5	2.8	15	3.2	2.7	8.4	5.5	--
AU1	4.5-5.1	2.6	17	2.9	2.7	8.4	5.5	4.3
AU2	0-4.5	2.6	21	1.4	2.3	7.4	3.9	3.0
AU2	4.5-6.3	3.0	41	4.3	2.2	6.8	4.5	3.0
AU3	0-3	5.8	23	-10	0	1.9	0	--
AU3	3-6	3.1	18	3.8	2.7	7.9	6.3	4.6
AU4	0-2.1	2.3	75	3.7	3.2	9.7	6.3	5.0
AU4	2.1-3	2.5	115	3.0	2.8	8.4	6.1	--
AU5	0-3	2.2	18	2.4	2.9	8.7	4.5	--
AU5	3-7.5	2.5	18	1.7	2.5	7.6	4.3	--
AU6	0-3	2.4	72	2.9	2.7	8.9	5.6	4.8
AU6	3-4.5	2.9	103	1.8	2.3	7.1	3.3	--
OW112	0-0.5	4.4	6.5	1.6	--	--	--	--
OW115	0-0.5	4.2	6.5	0.7	--	--	--	--

[a] See Figure 41, page 104; AU = auger hole, OW = observation well

[b] Lime requirements determined from percent sulfur as measured by Leco Induction Furnace times 31.25. Gives the acidity that sulfur would produce

[c] Neutralization potential. Determined by Smith et al., 1974. A negative value indicates alkalinity

[d] Woodruff method commonly used for agricultural soils

[e] SMP method. Council on Soil Testing and Plant Analysis, 1974

[f] Five-minute incubation with heat. Abruna and Vincente, 1955

[g] Four-day incubation with heat. Dunn, 1943

[h] Dash indicates test not conducted on the sample

material is available on the east and west end of the disturbed area (represented by sites OW 112 and 115). Approximately 24,000 m^3 would be required. Further surveys and soil tests would have to conducted to determine the amount and exact location of suitable cover material.

It would be necessary to grade the surface of the mine area to eliminate the depression, facilitate runoff, and minimize infiltration (Figure 41, page 104). Shaping should be performed before covering with a growth-supporting medium. Ultimate stabilization of the area would be with vegetation. Johnston et al. (1975) of the U.S. Forest Service have conducted research on revegetation at this site. Their recommendation is that organic material be incorporated into the top 15 cm of the surface layer, that lime be applied to raise the pH to levels tolerable to plants (from 1.8 T/ha to 3.6 T/ha of lime, based on OW 112 and 115), and that fertilizer be applied at the equivalent rate of 111 kg N/ha. The area should be planted with native seed at the rate of 56 kg/ha. The native transplant material could be obtained near the McLaren site. This collection would require a sizeable commitment of manpower, and would probably require two seed harvesting years. Graded and "top soiled" areas not planted the first year would have to be protected with a mulch. In addition, straw mulch either crimped or tacked down with asphalt emulsion would be required to provide a favorable microclimate for the seed and young plants. A maintenance program to reseed areas that did not develop satisfactory vegetation would be needed for a few years following initial seeding. The total cost of reclamation at the McLaren mine site is estimated to be $292,100 (Table 19, page 107).

Other alternative control methods such as covering with plastic or other impermeable materials, and soil sealing with chemicals would not be a permanent solution to the problem.

The effectiveness of the proposed reclamation is difficult to estimate, since the exact source of the acid, heavy metals, etc., has not been pinpointed, especially during the critical snowmelt period. During construction an increase in sediment and other pollutants may occur if a severe storm occurs. However, since the area is small, grading and "soil" covering should take place rather rapidly. Areas not planted the first year would be protected with mulch.

If it is assumed that the grading and "soil covering" is effective in increasing runoff, decreasing infiltration, and minimizing mine waste/water contact, then a 90 percent improvement in water quality at site 109 could result during the runoff period. The runoff should increase by 25 percent. The total acid load during the runoff period in 1975 was 128,000 kg, and a 90 percent reduction would result in a remaining 12,800 kg of acid load. The groundwater yielded an acid load of 26,800 kg in water year 1975, and a 25 percent reduction would result in a remaining load of 19,900 kg. The total load was 154,800 kg, and after reclamation the load would be reduced to 32,700 kg or a decrease of 79 percent. A similar decrease in other water quality parameters could be expected.

TABLE 19. COST OF RECLAMATION AT McLAREN MINE SITE

Item	Quantity	Unit price	Total price
Grading			
Tailings material	20,600 m^3	\$3.30/m^3	\$68,000
Cover material	29,000 m^3	3.30/m^3	95,000
Diversion ditch along highwall			
Bentonite seal	4,500 kg	0.22/kg	1,000
Excavation	640 m^3	3.30/m^3	2,000
Drainage ditch for seeps			
Bentonite	1,450 kg	0.22/kg	300
Gravel	23 m^3	13.00/m^3	300
Revegetation			
Collection and treatment of seed	385 kg	44.16/kg	17,000
Fertilizer	770 kg	0.55/kg	400
Lime	24.8 T	286.70/T	7,100
Planting	6.9 ha	1,450/ha	10,000
Mulch	3.1×10^4 kg	0.32/kg	10,000
Maintenance	1 Job	5,000/Job	5,000
Engineering			
Soil samples, surveys, construction inspection, etc.			50,000
Indirect cost			26,000
		TOTAL	\$292,100

Glengary Mine Area

The major sources of the pollutants in the Fisher Creek drainage at the Glengary mine site are: (1) the mine adits, and (2) the runoff waters passing over the mine wastes. The entire acid load of the two sources was measured at site 207. The discharge and load from the mine adit were measured at site 205. The mine adit contributed approximately 48 percent of the acid load measured at site 207. However, it must be realized that some of the load settled out between the sources and site 207.

Several alternative solutions to the adit problem are available. The inflow of water into the mine should be sealed off. As noted in Figure 5, page 16, approximately 58 percent of the inflow (it may be higher during high infiltration periods) enters the mine through the two risers. These risers extend to the surface at the disturbed areas below the Scotch Bonnet Mines. By proper grading and compaction around the risers and the waste areas, runoff could be increased and infiltration decreased to significantly reduce the flow from the adit. Sealing of the risers would also help to prevent surface water from entering the mine adit. In addition to sealing the risers, the adits could be sealed with an air or bulkhead seal. An air seal would prevent air from entering the tunnel but allow water to exit (Figure 42, page 109). Since pyrite is a major source of the acid, the lack of air in the tunnel should result in a reduction in the oxidation of pyrite within the mine. An air seal would be a wall constructed of concrete bricks and would not be an impossible barrier to remove if the mine were to be opened at a future date. Because of the limited entries into this mine, the deep cover, and small size of the tunnel system, this method might be effective in this situation. An air seal would have to be constructed at each of the two adits into the mine.

A bulkhead seal would be composed of an impermeable plug in each of the mine adits that would prevent water from discharging from the mine (Figure 43, page 109) and ultimately cause flooding of the works. The submerged condition would prevent pyrite oxidation and acid formation. The relatively level nature of this tunnel, with low heads, great amounts of overburden, and a thick outcrop, makes it appear that a bulkhead seal would be physically feasible. Further investigations regarding the tunnel, geology, and rock strength would be required before the exact location and size of the bulkhead could be determined. Sealing of the adits with a bulkhead would probably be opposed by the mine owners because of the permanent nature of the seal and the mineral value still in the mine.

The acid contribution from the mine waste could be controlled by grading the wastes and dumps to facilitate runoff (Figure 44, page 110) and by covering them with a soil-like material. The graded areas should have lime and fertilizer applied, be seeded with native vegetation, and have mulch added. A revegetation program similar to that proposed for the McLaren mine should be used. As noted in Table 20, page 111, suitable topsoil material is available in the upper Glengary area. The mine waste near the adit should be graded and covered with soil cover material obtained from the upper area. The lower waste could be hauled to the upper waste area and buried with the waste material at that site. However, this alternative of hauling the lower waste material is not deemed feasible because of the poor hauling road, steepness of the road, and the large volume of waste material to be moved. The total costs for reclamation of the Glengary mine site are estimated in Table 21, page 112.

The effectiveness of the above procedures may be estimated in the following way:

1. The total acid load from the mine (site 205) is 13,400 kg per year. An air seal would reduce the acid load by 40 to 70 percent. If a 66.7 percent reduction in load is assumed, the air seal reduces the acid load by 8,900 kg per year. A bulkhead seal would reduce the acid load by 80 to 100 percent. If we assume a 95 percent reduction, the bulkhead seal would reduce the acid load by 12,700 kg per year.

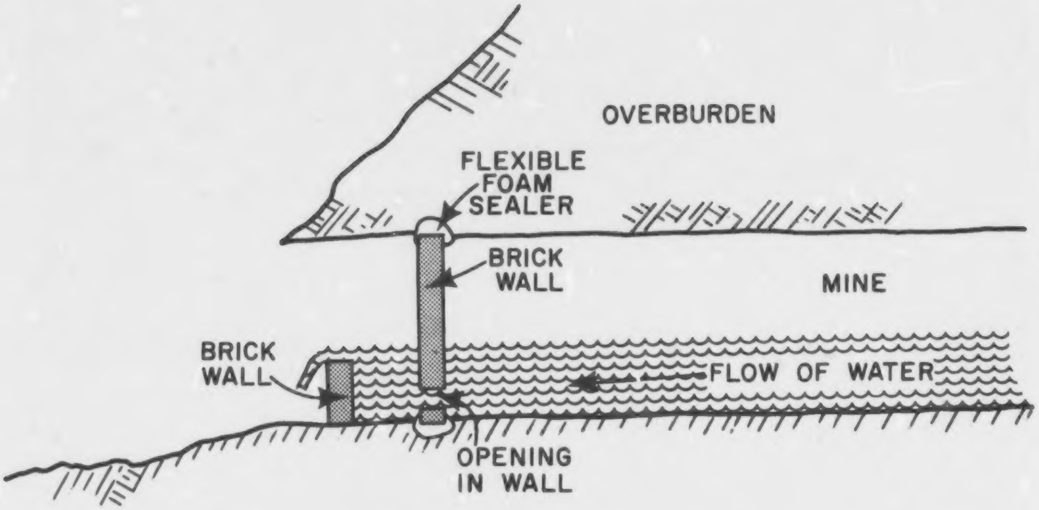

OVERBURDEN
FLEXIBLE FOAM SEALER
BRICK WALL
MINE
BRICK WALL
FLOW OF WATER
OPENING IN WALL

FIGURE 42 **Cross section of air seal.**

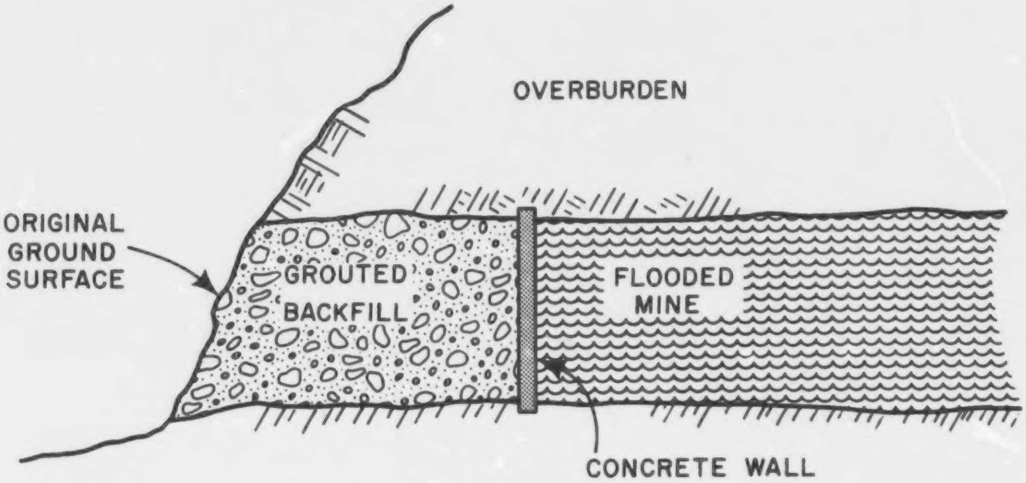

OVERBURDEN
ORIGINAL GROUND SURFACE
GROUTED BACKFILL
FLOODED MINE
CONCRETE WALL

FIGURE 43 **Cross section of bulkhead seal.**

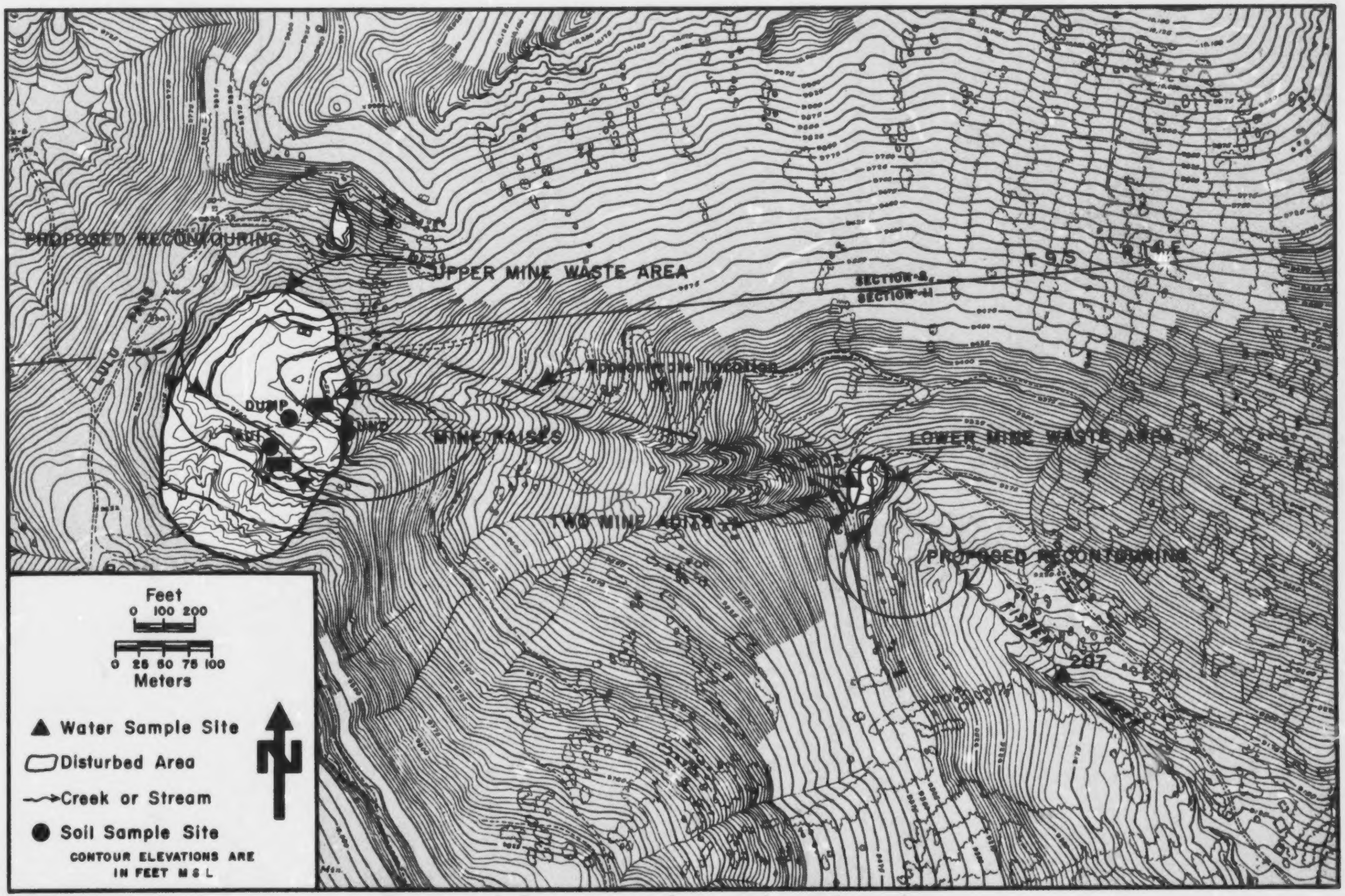

PROPOSED RECONTOURING
UPPER MINE WASTE AREA
T 9 S R 14 E
SECTION 2
SECTION 11
Approximate location of mine
LULU PASS
DUMP
MINE RAISES
LOWER MINE WASTE AREA
205
TWO MINE ADITS
PROPOSED RECONTOURING
FISHER
207
Feet
0 100 200
0 25 50 75 100
Meters
Water Sample Site
Disturbed Area
Creek or Stream
Soil Sample Site
CONTOUR ELEVATIONS ARE IN FEET M S L
N

FIGURE 44 Proposed Glengary mine reclamation plan.

TABLE 20. CHARACTERISTICS OF MINE WASTE MATERIALS AT GLENGARY MINE SITE

			Lime requirements[a] Metric tons per hectare				
Site[b] no.	Depth (m)	pH	From % S	Neut.[c] poten.	Woodruff	SMP	5-min incub.
AU1	0-1.5	2.8	28	-3.1	2.7	7.6	4.9
AU1	1.5-3	3.1	15	-2.1	2.7	1.6	4.5
AU1	3-4.5	3.2	104	-2.8	2.3	6.3	4.0
AU1	4.5-6	3.9	305	-1.8	1.8	5.0	3.0
AU1	6-7.5	3.6	167	-1.7	--[d]	--	--
AU1	7.5-9	4.1	281	0	--	--	--
AU1	9-10.5	3.9	363	0.7	--	--	--
AU1	10.5-12	3.7	362	0.5	--	--	--
AU1	12-13.5	3.7	200	1.2	--	--	--
UND	0-0.5	5.1	1.4	1.2	0.5	3.8	1.6
UND	0.5-1	5.0	1.4	0.4	0	1.9	--
UND	1-2	5.6	1.4	0.4	0	1.9	--
UND	2-2.5	4.1	8.4	0.5	0.7	5.0	1.7
DUMP	0-0.5	2.8	74.5	-3.3	2.8	7.9	4.8
DUMP	1.5-1.8	3.1	29.6	-2.2	2.5	6.8	3.6
DUMP	2.4-2.7	3.3	14.0	-1.6	2.9	7.9	4.6

[a] Methods used for determining lime requirements are the same as those described in Table 18, page 105. The four-day incubation test was not conducted on the above samples.

[b] See Figure 44, page 110; AU = auger hole, UND = undisturbed soil, DUMP = dump material.

[c] Negative value means alkalinity.

[d] Dash indicates sample not tested.

2. The total acid load from the upper Glengary mine area (load at site 207 minus load at site 205) during the snowmelt period is 14,700 kg. If we assume a 90 percent reduction in acid load from grading and covering the mine wastes, the load reduction is 13,200 kg.

If an air seal is constructed in the mine adit and the mine wastes are graded and covered, we could expect an acid load of 5,900 kg, a 79 percent reduction of the load at site 207. If a bulk seal is installed in the mine and the mine wastes are graded and covered, the acid load at site 207 would be 2,100 kg, a reduction of 93 percent. A similar decrease in other water quality parameters could be expected.

TABLE 21. COST OF RECLAMATION AT GLENGARY MINE SITE

Item	Quantity	Unit price	Total price
Infiltration control			
Grading			
Upper dump	9,300 m^3	\$3.30/m^3	\$30,700
Lower dump	4,500 m^3	3.30/m^3	14,900
Revegetation			
Collection of seed	175 kg	44.16/kg	7,700
Fertilizer	350 kg	0.55/kg	200
Lime	11.2 T	286.7/T	3,200
Planting	3.1 ha	1,450/ha	4,500
Mulch	1.4×10^4 kg	0.32/kg	4,500
Maintenance	1 Job	2,000/Job	2,000
Engineering			
Soil samples, surveys, construction inspection, etc.			\$20,000
Indirect Cost			8,000
		TOTAL	\$95,700
Mine sealing			
Air seal			
Clean two adits			\$ 4,000
Construct two seals			10,000
Engineering			2,000
Indirect cost			2,000
		TOTAL	\$18,000
Bulkhead seal			
Clean two adits			\$ 4,000
Construction of two seals			10,000
Grouting			10,000
Engineering			25,000
Geologic investigation, borings, construction inspection, plans, etc.			
Indirect cost			5,000
		TOTAL	\$54,000

McLaren Mill Area

The source of pollution at the McLaren mill area is the mill tailings pile. Water entering the tailings material from Soda Butte Creek, from rain and snowmelt on the tailings, and from runoff from the drainage above the pile passes through the tailings and discharges into Soda Butte Creek, thus polluting Soda Butte Creek below the tailings pile. The following alternatives are available to reduce the pollutant loads that enter Soda Butte Creek: (1) mill tailings removal, (2) effluent treatment, and (3) infiltration control.

Mill Tailings Removal

One alternative for reducing the pollution to Soda Butte Creek is to remove the tailings material. The actual removal would involve stripping the existing topsoil material from the tailings pile, stock-piling the topsoil, and using it for revegetation once the tailings material is removed. Removal of the tailings should be conducted in such a way as to prevent the tailings material from being washed into Soda Butte Creek. This may be accomplished by starting excavation on the west (downstream) side of the dump and excavating to the east. Also, Soda Butte Creek should be isolated from the dump by piping the flows around the dump during excavation. A small dam should be built below the tailings to catch and treat sediment and polluted flows from the tailings during excavation. Once all of the tailings material is removed, Soda Butte Creek should be rechanneled back to its location before tailings were placed in the channel. The topsoil should be replaced on the disturbed area, fertilized, and planted with grass seed suitable for the area. Figure 45, page 114, is a cross section of Soda Butte Creek before and after removal of the mill tailings pile.

While considering removal of the mill dump, we must examine what will be done with the tailings material. One possibility is to haul the material to a smelter, concentrate the tailings, and recover the minerals still left in the tailings. Total value of the minerals is estimated at $4,747 million (March 1977 prices). The nearest smelter which could recover the metals is located at East Helena, Montana, 500 km from Cooke City. It was assumed for this alternative that the cost of concentrating and recovering the metals would be offset by the sale of minerals recovered. The cost of hauling the tailings is the most expensive item of this alternative. Since Yellowstone National Park and Beartooth Pass probably physically prohibit hauling of the tailings by these routes, the tailings material would have to be hauled down the Sunlight Basin road (Wyoming 292) to be loaded on the railroad near Belfry, Montana.

Another possibility for this alternative is to relocate the tailings at another site in the Cooke City area. An ideal site for the new tailings pile should have the following characteristics: (1) be located not more than 8 km from present sites, (2) be located on a rise or summit and definitely not in a creek or stream bottom, (3) not be influenced by groundwater or surface runoff from adjacent areas, (4) be located in an area of impermeable soil, (5) have a source of topsoil at or near the site, and (6) be in an area free from drifts of snow. The exact shape of the

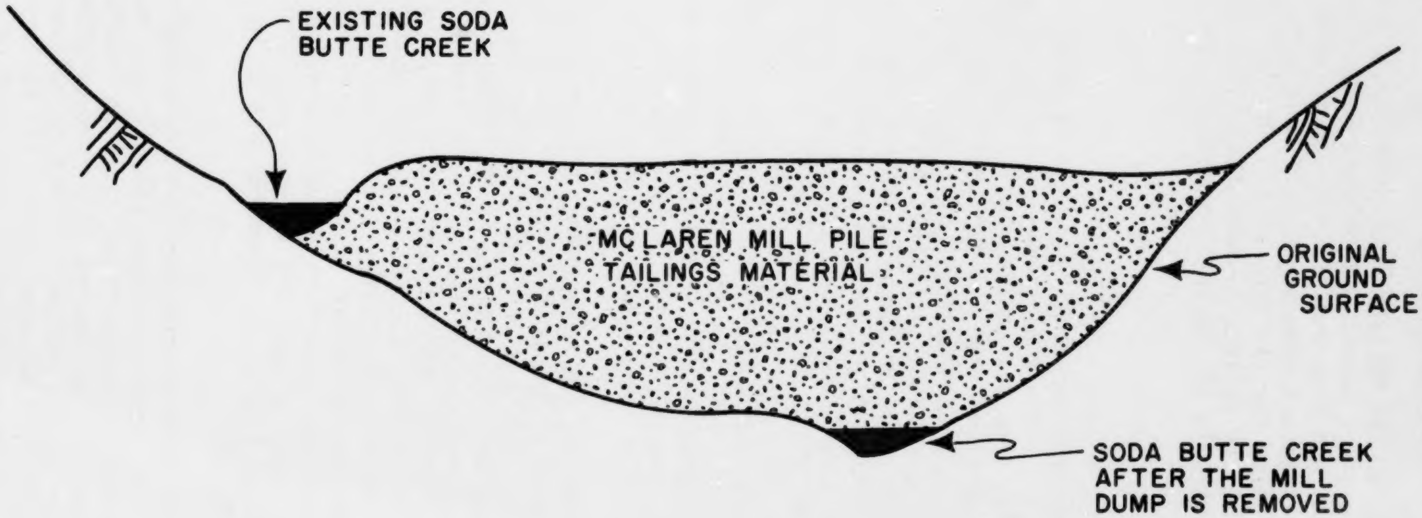

EXISTING SODA BUTTE CREEK
MC LAREN MILL PILE TAILINGS MATERIAL
ORIGINAL GROUND SURFACE
SODA BUTTE CREEK AFTER THE MILL DUMP IS REMOVED

FIGURE 45 Cross section of McLaren mill pile and Soda Butte Creek before and after tailings removal.

new tailings pile will have to be determined once the exact location for the new pile is located; however, the pile will probably be conical in shape and require approximately 2.5 ha of land. During construction of the new dump, the tailings should be compacted to maximum density. After construction, the pile should be covered with 0.5 m of topsoil, have fertilizer added, and be seeded with grass suitable for the area.

A third possibility for disposal of the mill tailings material would be to bury it at an underground disposal site such as an old mine. If a mine or several mines were found that had enough volume for the tailings, they could be dumped into vertical shafts or sluiced into horizontal tunnels.

The cost of removing the mill tailings is given in Table 22.

TABLE 22. COST OF REMOVING McLAREN MILL TAILINGS

Item	Quantity	Unit price	Total price
Excavation site			
Topsoil			
Removal and replacement	25,000 m^3	\$ 6.50/m^3	\$162,500
Tailings excavation	87,000 m^3	0.75/m^3	65,300
Sediment dam	750 m^3	6.50/m^3	4,900
Treatment during construction (lime)	3.5 T	286.70/T	1,000
Soda Butte rerouting pipe (61 cm diam.)	300 m	39.80/m	11,950
Fertilizer and seeding	4.0 ha	1,750/ha	7,000
Engineering and indirect cost			50,000
		TOTAL	\$302,650
Disposal site			
Smelting			
Haul - 500 km	87,000 m^3	0.07/m^3km	\$3,045,000
New site			
Topsoil			
Remove and replace	7,700 m^3	6.50/m^3	50,000
Haul - 8 km	87,000 m^3	0.07/m^3km	48,700
Compaction	87,000 m^3	0.13/m^3	11,300
Fertilizer and seed	2.5 ha	1,750/ha	4,400
Engineering and indirect cost			25,000
		TOTAL	\$139,400
Underground disposal			
Haul - 8 km	87,000 m^3	0.07/m^3km	48,700
Engineering and indirect cost			20,000
		TOTAL	\$68,700

Removing the mine tailings at Cooke City would result in a 100 percent reduction in pollutant load in Soda Butte Creek from the tailings pile. The complete reduction would probably not be realized until several years after removal since some polluted groundwater would have to drain from the area that surrounded the tailings pile. It would also take several years for Soda Butte Creek to stabilize once it is rerouted back to its old channel, now beneath the tailings pile.

The AMD problem at Cooke City would be solved if the tailings pile is removed, but the potential for AMD may exist at sites where the pile would be relocated. If the tailings are sent to a smelter, the potential for pollution problems exists at the smelter waste site; however, it is hoped that those sites would not create environmental problems. The alternative of relocating the tailings to another site could create AMD problems at that site. As noted in the characteristics of an ideal site for the new tailings pile, care must be taken in selecting a site that is essentially isolated from any groundwater or surface water that may infiltrate the tailings material. If the pile is properly compacted and located at an ideal site, AMD from the new tailings pile should be zero. The last alternative, dumping the tailings in old mines, also has the potential for creating pollution problems. Care must be taken once the mine has been filled with tailings so that all AMD from the mines is treated or the mines are sealed. These problems can only be solved once the mines to be filled are selected and analyzed for AMD potential.

Effluent Treatment

The second alternative for reducing the AMD at the McLaren mill area is to treat the effluent from the tailings pile. Basically this would be accomplished by installing a dike below the tailings pile to collect all of the seeps, treating this polluted water, and building a dam below the dike to be used as a settling pond for the treated water. The location of the dike, treating plant, and settling pond are shown in Figure 46, page 117. Treatment of the effluent from the tailings pile should be with a typical lime neutralization process using hydrated lime. A schematic diagram of the treatment plant is shown in Figure 47, page 118. The treatment plant should be designed for a maximum flow of 28 lps. Based upon an acidity value of 150 mg/l at maximum flows, the maximum lime requirement is about 340 kg per day. For low flows, such as 2.8 lps, the lime requirements are 34 kg per day. Flows greater than 28 lps, which would occur rarely, would be passed by the lime treatment plant. The amount of lime added to the effluent would be controlled by a device measuring the flow of water passing through the treatment plant. Once the lime has been added to the effluent, it would flow by gravity over baffles to induce mixing and aeration and into the settling pond. The settling pond should retain the treated effluent for no less than 12 hours, and then flow by gravity to Soda Butte Creek. The settling pond would be 7,000 m^3 in size and would need cleaning approximately once every 50 years. Soda Butte Creek would have to be lined with riprap next to the settling pond dam to prevent erosion of the dam. The estimated cost of treating the effluent is itemized in Table 23, page 119.

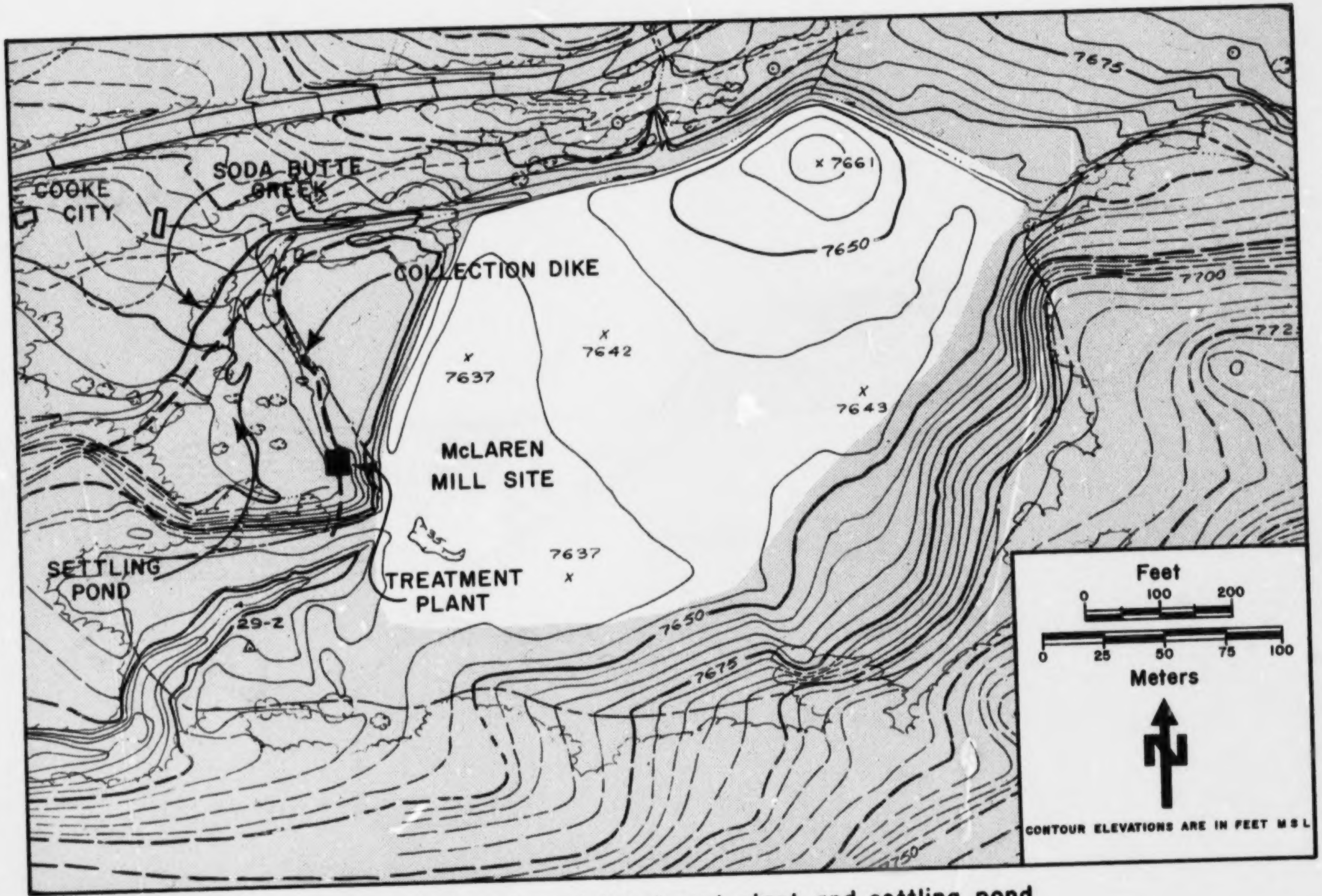

SODA BUTTE CREEK
COOKE CITY
COLLECTION DIKE
McLAREN MILL SITE
TREATMENT PLANT
SETTLING POND
29-Z
7637
7642
7643
7661
7637
7650
7675
7700
7725
7750
Feet
0
100
200
0
25
50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET MSL

FIGURE 46

Proposed location of treatment plant and settling pond at McLaren mill area.

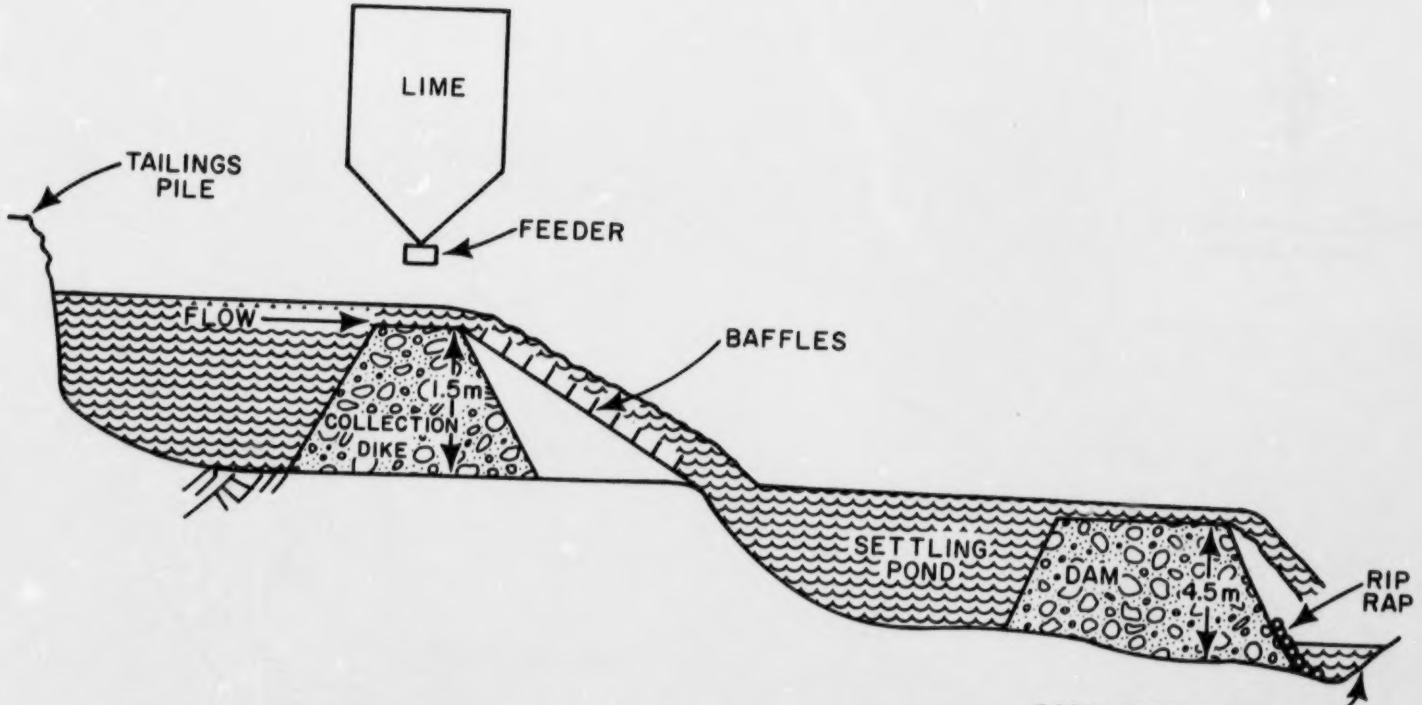

TAILINGS PILE
LIME
FEEDER
FLOW
BAFFLES
1.5m
COLLECTION DIKE
SETTLING POND
DAM
4.5m
RIP RAP
SODA BUTTE CREEK

FIGURE 47

Proposed lime neutralization process at McLaren mill area.

TABLE 23. COST OF TREATING EFFLUENT FROM McLAREN MILL TAILINGS

Item	Quantity	Unit price	Total price
Collection dam and dike	4,600 m^3	\$ 3.30/m^3	\$151,800
Riprap	100 m^3	130/m^3	1,300
Treatment plant	1	250,000 each	250,000
Engineering and indirect cost			80,000
		TOTAL	\$483,100
Annual cost			
Lime	50 T	\$268.70/T	\$ 14,300
Maintenance (wages, electric)	1 Job	1 Job	15,000
			29,300

By treating the effluent from the tailings pile with lime, we could expect a reduction in pollutant load of 80 to 90 percent. If the total annual iron load from the tailings pile (sites 320 and 321) is 35,680 kg of iron, an 80 percent reduction would reduce the iron load to 7,140 kg per year.

The physical feasibility of operating a lime treatment plant below the tailings pile is very limited. The great snow depths and very cold weather characteristic of the area would limit access to and operation of the treatment plant. Cold weather in the winter months would probably freeze any baffles and weirs at the treatment plant, as well as freezing the collection and settling ponds.

Infiltration Control

The last alternative for controlling the AMD from the McLaren mill dump is to control the inflow into and out of the tailings pile. This can be accomplished by resealing the dam on the lower end of the tailings pile and rechanneling Soda Butte Creek. The dam at the lower end of the tailings pile would have to be resealed with a layer of impervious material (Figure 48, page 120). The impervious seal should extend from bedrock or an impervious horizontal zone up to the top of the dam at elevation 2,329 m. The dam should extend from the north side of Soda Butte Creek, across Soda Butte Creek, and across the face of the tailings pile to the spillway on the south side of the tailings pile (Figure 49, page 121). The existing Soda Butte Creek along the north side of the tailings pile should be filled with material to an elevation of 2,330 m. Source of the material could be the high spot in the north central part of the tailings pile. A new Soda Butte Creek channel should be cut in the hillside immediately to the north of the

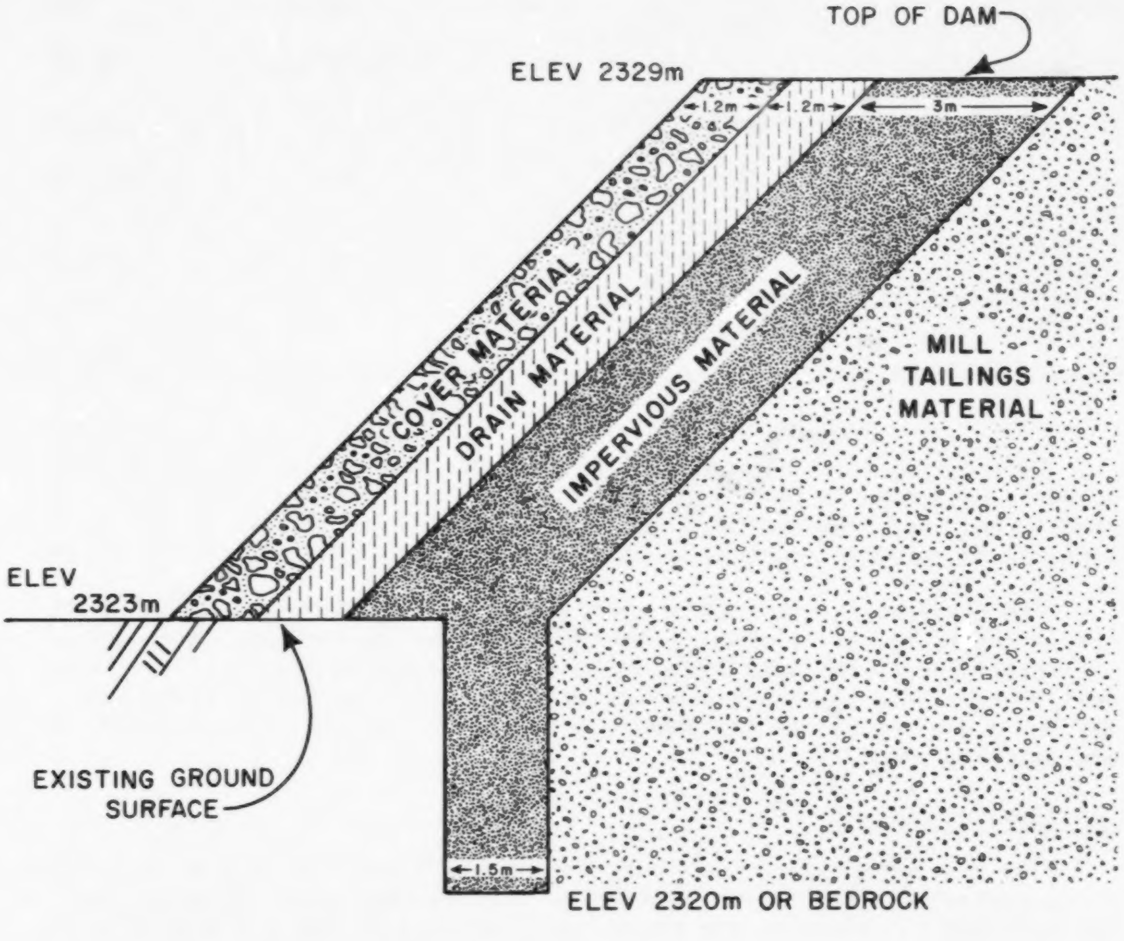

TOP OF DAM
ELEV 2329m
1.2m
1.2m
3m
COVER MATERIAL
DRAIN MATERIAL
IMPERVIOUS MATERIAL
MILL TAILINGS MATERIAL
ELEV 2323m
EXISTING GROUND SURFACE
1.5m
ELEV 2320m OR BEDROCK

FIGURE 48 Cross section of proposed dam at McLaren mill tailings pile.

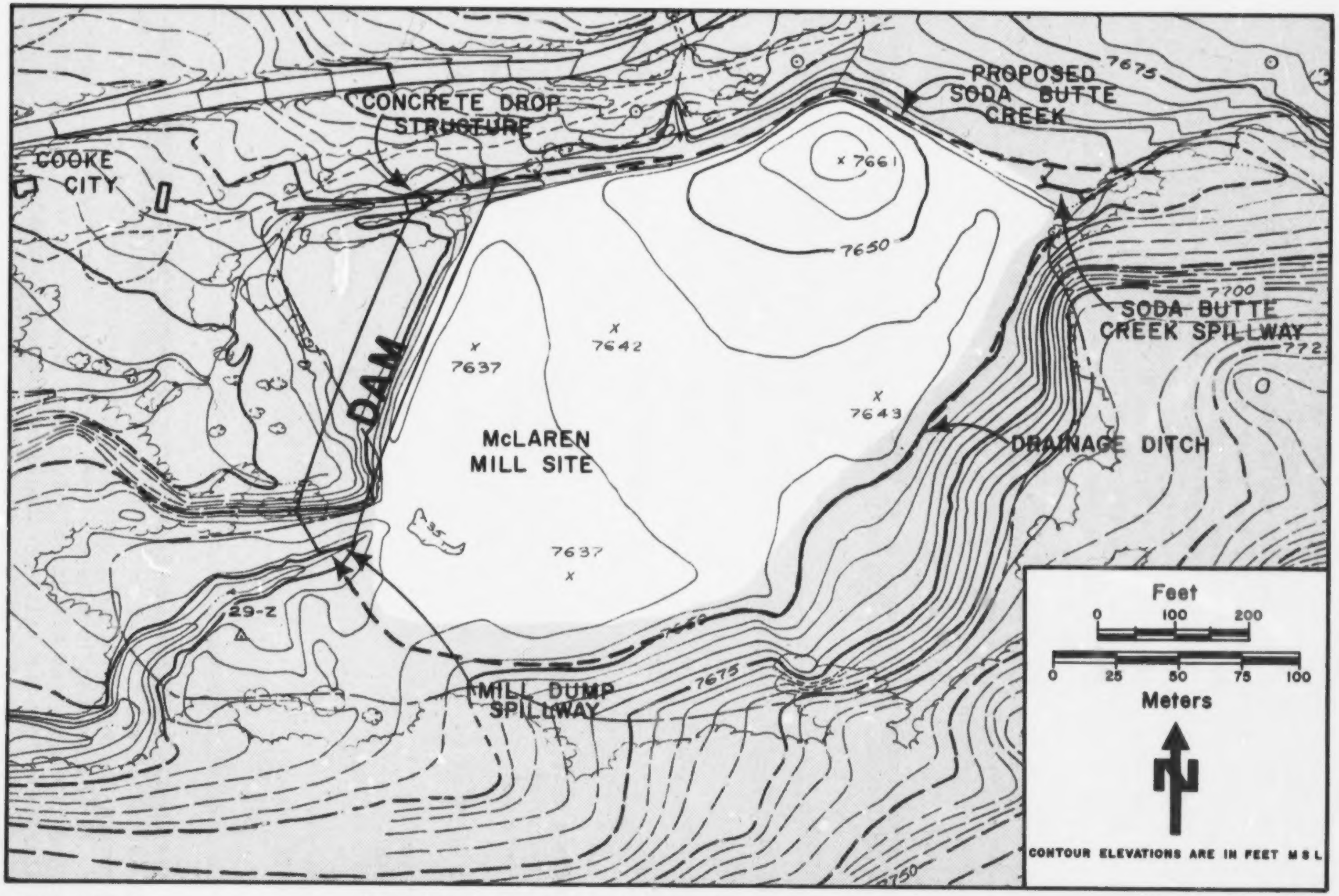

CONCRETE DROP STRUCTURE
COOKE CITY
PROPOSED SODA BUTTE CREEK
7675
x 7661
7650
SODA BUTTE CREEK SPILLWAY
7700
772
DAM
x 7637
x 7642
x 7643
McLAREN MILL SITE
DRAINAGE DITCH
35
7637 x
29-Z
7650
7675
MILL DUMP SPILLWAY
7750
Feet
0
100
200
0
25
50
75
100
Meters
CONTOUR ELEVATIONS ARE IN FEET MSL

FIGURE 49 Proposed location of new dam and Soda Butte Creek channel at the McLaren mill area.

existing Soda Butte Creek. The new channel would intercept Soda Butte Creek 15 m above the tailings pile and carry Soda Butte Creek flows to the north end of the new dam. The new channel would have a 6.1 m bottom, 2:1 side slopes, 2.5 m top width dike along the south edge of the new channel, and have a slope of 0.002 m/m. A spillway in the dike at the upper end of the tailings pile would allow flows greater than the 100-year flood to spill from the new Soda Butte Creek channel, across the mill dump to the spillway on the west end of the dump, and eventually into Soda Butte Creek. The new channel should be lined with bentonite. At the end of the new Soda Butte Creek channel, at the north end of the new dam, a 6.1 m concrete drop structure would be built to carry Soda Butte Creek flows from the new channel above the dam, to the existing channel below the tailings pile. A drainage ditch would also have to be built along the south edge of the tailings pile to drain runoff from the hillside away from the mill dump. An itemized cost of this alternative is presented in Table 24.

TABLE 24. COST OF CONTROLLING INFILTRATION INTO THE McLAREN MILL DUMP

Item	Quantity	Unit price	Total price
Fill existing Soda Butte Creek channel	3,600 m^3	\$ 3.30/m^3	\$ 11,900
New Soda Butte Creek	3,900 m^3	3.30/m^3	12,900
Bentonite	49,000 kg	0.11/kg	5,400
Dam			
Impervious material	3,540 m^3	6.60/m^3	23,400
Drain material	1,130 m^3	3.30/m^3	3,700
Cover material	1,130 m^3	3.30/m^3	3,700
Drainage ditch	45 m^3	3.30/m^3	150
Drop structure			
Concrete	109 m^3	780/m^3	85,000
Reinforcing steel	5,150 kg	1.32/kg	6,800
Riprap	70 m^3	13.00/m^3	910
Excavation	760 m^3	1.65/m^3	1,250
Backfill	490 m^3	3.30/m^3	1,600
		TOTAL	\$156,710

The alternative of reducing the effluent from the McLaren tailings pile should reduce the pollutant load dumped into Soda Butte Creek by 95 to 100 percent. If the new dam is extended down to bedrock or an impervious layer beneath the tailings, and effectively seals the downstream face of the pile, the infiltration from the tailings should be completely stopped.

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APPENDIX A: CONVERSION FACTORS

Metric System

megameter	=	1,000,000	meters
myriameter	=	10,000	meters
kilometer*	=	1,000	meters
hectometer	=	100	meters
decameter	=	10	meters
meter*	=	1	meters
decimeter	=	.1	meters
centimeter*	=	.01	meters
millimeter*	=	.001	meters
micrometer	=	.000001	meters

*commonly used units

Length

Multiply. . .	By. . .	To obtain. . .
miles	1.609	kilometers
yards	.9144	meters
feet	.3048	meters
inches	2.54	centimeters
inches	25.4	millimeters
kilometers	.631	miles
meters	1.094	yards
meters	3.2809	feet
centimeters	.3937	inches
millimeters	.03937	inches

Area

Multiply. . .	By. . .	To obtain. . .
square miles	2.59	square kilometers
acres	.004047	square kilometers
acres	4,047	square meters
square feet	.0929	square meters
square inches	6.4516	square centimeters
square miles	640	acres
acres	43,560	square feet
square kilometers	.3861	square miles
square meters	.000247	acres
square meters	10.764	square feet
square centimeters	.155	square inches

Volume

Multiply. . .	By. . .	To obtain. . .
acre-feet	.001233	cubic hectometers
acre-feet	1,233	cubic meters
cubic feet	.02832	cubic meters
cubic feet	28.32	liters
U.S. gallons	3.785	liters
acre-feet	358,851	U.S. gallons
cubic feet	7.48	U.S. gallons
million gallons	3.07	acre-feet
cubic meters	.00081	acre-feet
cubic meters	35.3147	cubic feet
liters	.0353	cubic feet
liters	.2642	U.S. gallons

Mass

Multiply. . .	By. . .	To obtain. . .
pounds	.4536	kilograms
tons (short)	.9072	tons (metric)
kilograms	2.2046	pounds
tons (metirc)	1.1023	tons (short)

Flow

Multiply. . .	By. . .	To obtain. . .
gallons per minute	.06309	liters per second
cubic feet per second	.02832	cubic meters per second
cubic feet per second	28.32	liters per second
gallons per minute	.00223	cubic feet per second
cubic feet per second	1.9835	acre-feet per day
cubic feet per second	40	Montana Miners inch
cubic feet per second	448.8	U.S. gallons per minute
cubic feet per second	724	acre-feet per year
liters per second	.03531	cubic feet per second
liters per second	15.85	gallons per minute
cubic meters per second	35.31	cubic feet per second

Velocity

Multiply. . .	By. . .	To obtain. . .
feet per second	.3048	meters per second
feet per second	1.097	kilometers per hour
feet per second	30.48	centimeters per second
feet per second	.68	miles per hour
miles per hour	1.4666	feet per second
meters per second	3.2808	feet per second

TEMPERATURE

The values in the body of the table give the equivalent, in degrees Fahrenheit, of the temperatures indicated in degrees Centigrade at the top and side.

°C	0	1	2	3	4	5	6	7	8	9
100	212.0	213.8	215.6	217.4	219.2	221.0	222.8	224.6	226.4	228.2
90	194.0	195.8	197.6	199.4	201.2	203.0	204.8	206.6	208.4	210.2
80	176.0	177.8	179.6	181.4	183.2	185.0	186.8	188.6	190.4	192.2
70	158.0	159.8	161.6	163.4	165.2	167.0	168.8	170.6	172.4	174.2
60	140.0	141.8	143.6	145.4	147.2	149.0	150.8	152.6	154.4	156.2
50	122.0	123.8	125.6	127.4	129.2	131.0	132.8	134.6	136.4	138.2
40	104.0	105.8	107.6	109.4	111.2	113.0	114.8	116.6	118.4	120.2
30	86.0	87.8	89.6	91.4	93.2	95.0	96.8	98.6	100.4	102.2
20	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4	84.2
10	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2
0	32.0	33.8	35.6	37.4	39.2	41.0	42.8	44.6	46.4	48.2
-0	32.0	30.2	28.4	26.6	24.8	23.0	21.2	19.4	17.6	15.8
-10	14.0	12.2	10.4	8.6	6.8	5.0	3.2	1.4	-0.4	-2.2
-20	-4.0	-5.8	-7.6	-9.4	-11.2	-13.0	-14.8	-16.6	-18.4	-20.2
-30	-22.0	-23.8	-25.6	-27.4	-29.2	-31.0	-32.8	-34.6	-36.4	-38.2
-40	-40.0	-41.8	-43.6	-45.5	-47.2	-49.0	-50.8	-52.6	-54.4	-56.2
-50	-58.0	-59.8	-61.6	-63.4	-65.2	-67.0	-68.8	-70.6	-72.4	-74.2
-60	-76.0	-77.8	-79.6	-81.4	-83.2	-85.0	-86.8	-88.6	-90.4	-92.2
-70	-94.0	-95.8	-97.6	-99.4	-101.2	-103.0	-104.8	-106.6	-108.4	-110.2
-80	-112.0	-113.8	-115.6	-117.4	-119.2	-121.0	-122.8	-124.6	-126.4	-128.2
-90	-130.0	-131.8	-133.6	-135.4	-137.2	-139.0	-140.8	-142.6	-144.4	-146.2
-100	-148.0	-149.9	-151.6	-153.4	-155.2	-157.0	-158.8	-160.6	-162.4	-164.2

APPENDIX B

CLIMATIC DATA

The weather station closest to the project area is in Cooke City, Montana, at an altitude of 2,302 m. Table B-1 summarizes the monthly temperature data and Table B-2 summarizes the monthly precipitation data. These data were compiled from "Climatological Data", published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, through their National Climatic Center, Federal Building, Ashville, North Carolina 28801.

TABLE B-1. SUMMARY OF MONTHLY TEMPERATURE DATA AT COOKE CITY, MONTANA (^{o}C)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Ave
1967	--	--	--	--	--	--	--	--	--	--	-4.61	-11.94	
1968	-10.06	-5.44	-3.00	-2.56	3.94	8.67	13.67	10.33	7.28	2.22	-6.22	-11.11	0.64
1969	-8.56	-7.94	-7.22	1.89	6.33	7.50	12.28	14.00	9.61	-0.61	-4.67	-8.61	1.17
1970	-8.44	-5.50	-6.44	-4.83	4.44	10.11	13.33	14.33	5.28	-0.06	-3.83	-9.33	0.75
1971	-8.78	-8.50	-5.89	-1.28	5.44	9.56	12.39	15.28	5.72	1.22	-4.83	-10.67	0.81
1972	-11.06	-6.94	-2.11	-0.17	5.11	10.00	11.67	12.61	5.67	2.00	-5.61	-12.00	0.76
1973	-10.94	-6.56	-4.72	-2.61	--	--	12.89	12.94	7.56	3.44	-4.72	-8.00	
1974	-10.56	-7.44	-4.94	0.61	2.94	10.56	14.22	11.06	8.00	3.72	-5.06	-10.94	1.01
1975	-11.83	-9.72	-6.56	-3.72	2.50	7.00	14.33	10.06	7.44	1.72	-7.31	-7.61	-0.31
1976	-4.00	-8.11	-8.06	0.00	5.61	8.22	13.83	11.44	8.89	--	--	--	
Ave	-9.36	-7.35	-5.44	-1.41	4.54	8.96	13.18	12.45	7.27	1.71	-5.21	-10.02	0.69

TABLE B-2. SUMMARY OF MONTHLY PRECIPITATION DATA AT COOKE CITY, MONTANA (mm)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Ave
1967	--	--	--	--	--	--	--	--	--	--	60.5	80.3	
1968	45.0	53.8	37.1	17.0	51.3	97.3	32.3	155.7	106.4	50.8	70.4	46.7	763.8
1969	133.6	24.9	12.7	40.4	59.7	109.5	55.1	17.3	47.0	34.5	67.6	57.9	660.1
1970	107.2	39.6	61.2	66.8	61.7	62.2	60.5	38.9	94.0	30.2	71.9	43.2	737.4
1971	115.1	66.5	64.0	43.2	23.4	30.5	56.4	42.4	60.2	37.3	49.3	66.0	654.3
1972	96.5	52.3	75.7	35.3	26.2	87.4	52.6	40.4	118.4	31.7	28.7	49.5	694.7
1973	27.2	10.4	18.0	61.7	--	--	27.2	44.2	73.7	14.5	57.4	75.7	
1974	68.8	38.1	115.6	24.9	76.7	69.1	29.0	66.5	14.7	46.7	18.0	47.8	615.9
1975	103.9	49.3	50.3	45.5	65.5	86.4	64.3	41.1	26.2	83.1	78.5	61.7	755.8
1976	84.1	83.6	53.9	64.3	28.7	90.9	33.3	46.2	90.2	--	--	--	
Ave	86.8	46.5	54.3	44.3	49.2	79.2	45.6	54.7	70.1	41.1	55.8	58.8	697.4

Dashes indicate data not recorded.
Maximum daily precipitation was 31.8 mm on June 5, 1974.

APPENDIX C

METHODS OF INVESTIGATION

Introduction

The purpose of this section is to provide an adequate discussion of the equipment and methods employed, so that the reader can evaluate the reliability of the data. This is particularly necessary for water quality sampling and sample handling, as methods and equipment used are in a state of continuous change and improvement.

Surface Water Hydrology

The 100, 200, and 300 series site numbers refer to the McLaren mine area, the Glengary mine area, and the McLaren mill site, respectively. Four weirs, three rectangular weirs constructed of plywood and one triangular weir constructed from boiler plate, were installed in 1974 at sample sites 109 (Daisy Creek), 207 (Fisher Creek), 322 (Soda Butte Creek), and 321 (mill site culvert weir), respectively. Staff gauges were installed on the sides of the plywood weirs to facilitate measuring the flow during periods of high runoff. Stilling wells with recorders were installed at the plywood weirs; however, these wells tended to freeze up during the spring runoff in 1975. Consequently many of the streamflow measurements for these sites were obtained by a Gurley (pigmy model) flow meter. These data were obtained by the local employee (Albert Brubaker), who was instructed in the measurement methods by the DNRC Hydrologist, Melvin McBeath.

Precipitation and temperature data were taken from "Climatological Data", a monthly publication of the U.S. Department of Commerce. The Cooke City weather station is located at an altitude of 2,302 m. Ten years of temperature and precipitation data were available at the close of this study and are presented in Appendix B.

Groundwater Hydrology

Routine water-level measurements in wells at the three research sites were obtained by the local employee using a steel tape graduated in hundredths of a foot. Elevations of the wells were surveyed by plane table methods from the nearest bench marks. Absolute elevation errors are thought to be less than 0.3 m at the mill site and less than 3 m at the mine sites. Relative elevation errors between wells at each site are believed to be less than 30.5 mm.

Fifteen cased wells installed in the tailings pond study area in 1973 and 1974 were used to measure water levels and to collect water samples for analysis. Nine cased wells were installed in 1974 at the mine sites, six on the McLaren property and three at the Glengary site. All of these wells were constructed by putting casing within a backhoe-dug hole and refilling the hole. The basic information about all of the wells is included in Appendix G.

Geologic Mapping

In the mine areas, mapping was begun on a scale of 25.4 mm = 61 m, but the structural complexities required scales as large as 25.4 mm = 3 m. The variability of exposures, ranging from 100 percent on open pit faces to zero percent on talus slopes, and the inability to extend the mapping of small features beneath covered areas led to the abandonment of detailed mapping. Major lithologic units, faults, and alteration were mapped from the south end of the McLaren mine area across Fisher Mountain to the upper adit on the west side of Scotch Bonnet Mountain. Variations in grain size and mafic mineral content of the igneous rocks were noted but were not thought to be of sufficient importance to justify delineating the boundaries of such variations. No irrefutable structural evidence was found indicating that the diorite dike adjacent to the felsite breccia on the north end of Fisher Mountain does predate the breccia, but the pervasive alteration and mineralization of the dike strongly supports this interpretation.

Water Sample Collection and Handling

The water samples collected in areas affected by sulfide mining are frequently in a state of disequilibrium. Metals capable of two or more oxidation states may be predominantly in the lower oxidation state, owing to oxygen depletion resulting from sulfide ion oxidation. As the affected waters interact with atmospheric oxygen in wells and mine seeps or as base-flow contribution to streams, oxidation of the metals in the lower valence state begins. Even if the sample bottles are gas tight, some additional oxygen is normally introduced while getting the sample into the collection bottle. Consequently, the unpreserved samples that the laboratory analyzes may be altered by the precipitation of metals oxidized to a higher valence state.

The following steps were taken to provide information about transient species with changing concentrations as a function of sample handling:

(1) Conductivity, pH, and temperature were measured in the field or shortly after collection on a routine basis.

(2) Samples from selected sites, for iron and aluminum analyses, were routinely sampled four ways: raw, raw acidified, filtered, and filtered acidified. Filtration was by positive pressure through 0.45 micron filters. Acidification employed the addition of one volume percent high-quality (J. T. Baker No. 5-9603) nitric acid, added from premeasured ampules.

(3) Specific conductance, pH, and oxidation-reduction (redox) potential were measured in the field at the time of sampling to evaluate the extent of disequilibrium at the time of collection. the redox values were repoducible with very little drift or error (± 3 millivolts), suggesting that these high-iron systems are very highly poised.

(4) "Total" metal values were obtained from samples at selected sites to compare with data collected by other agencies.

Because of the climatic and terrain conditions, some procedural problems were encountered. Winter access to the mine areas is difficult, snowmobiles being the only efficient means of travel. The machines used had very little cargo space, and one man could not carry both the necessary number of sample bottles and the necessary meters and filtration apparatus. Winter tests of the conductivity and pH meters under field conditions by a two-man team were not satisfactory, and the practice was abandoned.

Water samples collected from the wells must be viewed with some suspicion. The physical setting and equipment provided by the grantee required the use of shallow wells. As water levels declined in the fall, little water remained in these wells, and the samples collected were turbid. Part of this turbidity was undoubtedly due to the precipitation of ferric hydroxide within the wells. Some ferric hydroxide of colloidal size undoubtably passed through the 0.45 micron filters, resulting in slightly higher dissolved iron values. Cation-anion balances of both surface water and groundwater samples were generally good (differences of less than 2.5 percent, but for well samples containing iron in concentrations greater than 1,000 mg/l, larger differences occurred. This is attributed to the standard practice of calculating iron milliequivalents as Fe^{3+} when considerable $FeOH^{2+}$, Fe^{2+}, $Fe(OH)_2^{+}$, $FeSO_4^{+}$, and colloidal $Fe(OH)_3$ must have existed in solution.

One of the major problems in designing the collection program was related to biological questions. It was known that iron and aluminum in high concentrations are toxic to fish. The effect of particle size, particularly in the collodial region, was not known, and the question: "What fraction of the analytically determined iron and aluminum values are biologically active?" was partly responsible for the sample treatment procedures used. The practice of determining "total" metals employing an acid cook-down procedure was rejected by the Bureau investigators as not being relevant to the affected ecosystem. This makes comparison of data collected by Bureau personnel with data from investigators who have preferred "total" values somewhat risky, despite the one set of samples collected for "total" metal values.

Lastly, surface water samples were collected as grab samples because bottles for the depth-integrated sampler (DH-48) did not arrive until the end of the field season. The field procedure employed was to collect the sample approximately one-third of the way across the stream at a position one-third of the way up from the bottom. Nevertheless, this collection method undoubtedly introduced some additional sampling variability into the suspended sediment collected.

APPENDIX D

ACID MINE DRAINAGE EFFECTS ON STREAMS

Introduction

Mining activities at Cooke City have disturbed the natural conditions in that: (1) rock materials that had little contact with ground and surface waters have been disturbed and removed to land-surface or near-surface positions (as spoils and tailings), and (2) the mines themselves act as conduits for the transmission of groundwater. These activities have not significantly altered the chemical reactions that occur naturally in a mineralized area but have greatly accelerated the rate of these reactions. The accelerated reaction rate results from the vast increase of surface area exposed to air and water, compared with the undisturbed state. Removal of soils and overburden associated with the mining has increased the amount of recharge at the expense of the late-spring and early-summer runoff. Consequently, a great increase in permeability and in exposed sulfide-mineral surface area, combined with a greater volume of near-surface groundwater in contact with these sulfide minerals, has resulted in the conditions at the demonstration site.

Under both natural and mining-affected conditions, the composition and relative proportions of the various minerals and the chemical composition of infiltrating waters control the weathering reactions. The ore bodies mined at the Glengary and McLaren sites were replacement deposits, principally within the Meagher Formation; the major minerals in the ore zone are quartz, kaolinite, epidote, chlorite, pyrite, magnetite, and hematite, accompanied by a minor amount of chalcopyrite and traces of galena, sphalerite, and gold (Eyrich,1969). Pyrite is the predominate sulfide mineral (Lovering,1929; Eyrich,1969) in the ores mined at these sites. The hydrolysis of pyrite (FeS_2) and the oxidation of sulfide and ferrous iron ions control the rate at which significant amounts of iron and sulfur are intoduced into the waters. Acidity results from the oxidation of both iron and sulfur as described below.

The chemical reactions of major importance at the study sites may be classified as: (1) reactions that increase dissolved metal loads, (2) reactions that increase acidity, (3) reactions that decrease dissolved metal loads, and (4) reactions that decrease acidity. The role of oxygen concentrations in groundwater and surface water is an important controlling factor, which indirectly influences both metal loads and acidity.

The dissolution of pyrite, the most abundant sulfide mineral, may be represented as

$$FeS_{2(s)} + H_2O = Fe^{2+} + HS^- + OH^- + S^o_{(s)} \qquad (5)$$

for the hydrolysis reaction, and as

$$HS^- + S^o_{(s)} + H_2O + 7/2\ O_{2(g)} = 2\ SO_4^{2-} + 3\ H^+ \qquad (6)$$

for the oxidation reaction. At Cooke City, these two reactions are essentially coupled because sufficient oxygen is available in the shallow groundwater system to drive reaction (6) far to the right. Consequently, we see only the result of the combined reaction

$$FeS_{2(s)} + 7/2\ O_{2(g)} + H_2O = Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \qquad (4)$$

from the chemical analyses of groundwater samples. The oxygen uptake by reduced sulfur species and low pH values that result from reaction (4) cause the problems of heavy metals loads and acidity within the groundwater regime.

When oxygen content or pH increases, especially as the groundwater reaches the land surface as springs or seeps, a second group of chemical reactions may occur, which reduce the dissolved metal load but increase the amount of acid released to the water. The reactions consist of the oxidation of ferrous iron to ferric iron and the precipitation of the ferric species as ferric hydroxide. These reactions may be expressed as

$$2\ Fe^{2+} + \tfrac{1}{2}\ O_{2\,9g)} + 2\ H^+ = 2\ Fe^{3+} + H_2O \qquad (7)$$

and as

$$2\ Fe^{3+} + 6H_2O = 2\ Fe\ (OH)_{3(s)} + 6\ H^+ \qquad (8)$$

or the two equations may be combined (because the oxidation step is rate limiting) as

$$2\ Fe^{2+} + \tfrac{1}{2}\ O_{2(g)} + 5\ H_2O = 2\ Fe\ (OH)_{3(s)} + 4\ H^+ \qquad (9)$$

The oxidation of ferrous iron to ferric iron proceeds slowly in this environment [the oxidation rate is proportional to the partial pressure of oxygen times the hydroxyl ion activity squared (Stumm and Morgan, 1970; p. 534-540)]; under these stream conditions, hydroxyl activity is very low and colloidal ferric hydroxide should continue to form in the surface waters. The ferric hydroxide first precipitated will generally be amorphous. At present, data are not available to state whether aging of the precipitates from the toe of the mill site or in the streams results in the formation of the more stable phases goethite (FeO(OH)) or hematite (Fe_2O_3). Ferric hydroxide precipitates are very fine grained, and usually contain an appreciable amount of colloidal-size material (Langmuir and Whittemore,1971). This fine-grained precipitate tends to coalesce and form a crust with time, but during the spring runoff, the crust is broken up in many areas and dispersed. The result is that large amounts of ferric iron of relatively fine particle size are transported downstream, mainly as suspended load. The colloidal fraction of this material should have a very adverse effect upon fish inhabiting these reaches of the affected streams.

As the streams flow from the mining area, a third group of chemical reactions occur, which slowly raise the pH of the water. These are chemical weathering reactions, which consume hydrogen ions; typical reactions are the weathering of sodic plagioclase to form kaolinite

$$2NaAlSi_3O_{8(s)} + 9H_2O + 2H^+ = 2Na^+ + 4H_4SiO_4 + Al_2Si_2O_5(OH)_{4(s)} \qquad (10)$$

and the dissolution of limestone (a common acidity-abatement technique)

$$CaCO_{3(s)} + H^+ = Ca^{2+} + HCO_3^- \qquad (11)$$

By reactions such as these, the hydrogen ion content of the water is decreased, and the total dissolved solids increase downstream.

The most significant aspect of the above discussion is based upon the fact (Eyrich,1969; Lovering,1929) that pyrite is the dominant sulfide associated with mineralization. In developing a mass-transfer model based on the pyrite content of the disturbed areas, the limiting factors consist of: (1) the volume of pyrite in the spoils and tailings; and (2) the rate at which pyrite is oxidized. The acid contribution to the surface waters caused by the pyrite weathering process may be expressed by combining reactions (4) and (9) as

$$FeS_{2(s)} + 15/4\ O_{2(g)} + 7/2\ H_2O = Fe(OH)_{3(s)} + 2\ SO_4^{2-} + 4\ H^+ \qquad (12)$$

Thus, for each millimole of pyrite destroyed, four millimoles of hydrogen ion are released.

Data Base

Calculations used to determine the percent iron reaching the stream are based upon equation (4) and performed in the following manner,

$$\% \text{ Fe} = \left(3.44 \Big/ \left\{ \frac{(X - 11.3) \text{ mg/l } SO_4}{Y \text{ mg/l Fe}} \right\}\right) \times 100 \qquad (13)$$

where 3.44 is the ratio of SO_4^{2-} to Fe^{2+}, expressed in mg/l, produced by the hydrolysis of pyrite, and 11.3 mg/l is the average sulfate content of the three snow samples with complete analyses.

APPENDIX E

TABLE E-1 WATER QUALITY ANALYSIS DATA--McLAREN MINE AREA AND DAISY CREEK

Date	Flow (lps)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 101, T. 9 S., R. 14 E., Sec. 11 CBA																
7/25/74	0.57	2.77	1140.	242.	0.	306.	49.8	--[a]	43.0	14.8	--	--	--	--	--	--
8/15/74	0.28	2.88	954.	199.	0.	255.	52.2	--	28.6	14.0	--	--	--	--	--	--
9/16/74	0.03	3.04	1020.	231.	0.	258.	47.1	--	30.0	14.0	--	--	--	--	--	--
Station 102, T. 9 S., R. 14 E., Sec. 11 CBA																
8/21/73											0.02	58.6	4.98	0.05	--	--
7/25/74	6.23	2.50	2140.	806.	0.	842.	45.8	--	240.	31.1	--	--	--	--	--	--
8/13/74	1.70	2.55	2210.	886.	0.	999.	64.2	--	300.	37.0	--	--	--	--	--	--
10/15/74	0.57	2.63	2680.	946.	0.	1130.	76.4	--	284.	42.0	--	--	--	--	--	--
7/18/75	2.83	2.11	2290.	1120.	0.	1120.	40.4	318.	326.	41.6	--	--	--	--	--	--
8/5/75	1.42	2.05	1920.	800.	0.	878.	51.3	238.	246.	36.0	--	--	--	--	--	--
9/5/75	0.28	3.28	2000.	865.	0.	967.	62.3	268.	273.	37.2	--	--	--	--	--	--
Station 103, T. 9 S., R. 14 E., Sec. 11 CBD																
8/22/73	0.28	2.30	3120.	1180.	0.	1390.	88.4	--	318.	52.3	0.05	42.9	3.5	0.04	--	--
10/15/74	0.57	2.63	3260.	1520.	0.	1850.	96.1	--	312.	89.6	--	--	--	--	--	--
7/18/75	5.66	2.07	2470.	1190.	0.	1260.	3.43	285.	303.	59.5	--	--	--	--	--	--
8/5/75	2.27	2.02	2410.	1220.	0.	1280.	56.5	286.	286.	55.6	--	--	--	--	--	--
9/5/75	1.13	3.02	2460.	1200.	0.	1360.	71.7	280.	284.	57.5	--	--	--	--	--	--
Station 104, T. 9 S., R. 14 E., Sec. 11 CCB																
8/22/73	2.55	2.41	2890.	1120.	0.	1460.	96.7	--	191.	80.0	0.08	43.7	3.85	0.04	--	--
7/25/74	29.2	2.63	1840.	569.	0.	727.	38.4	--	101.	33.9	--	--	--	--	--	--
8/13/74	3.68	2.61	2310.	879.	0.	1080.	70.1	--	194.	61.0	--	--	--	--	--	--
9/16/74	0.85	2.63	2680.	921.	0.	1270.	67.7	--	178.	74.0	--	--	--	--	--	--
10/15/74	1.22	2.83	2530.	839.	0.	1320.	64.6	--	110.	91.4	--	--	--	--	--	--
7/18/75	12.2	2.17	1840.	674.	0.	778.	34.2	124.	118.	47.	--	--	--	--	--	--
8/5/75	5.10	2.01	2140.	977.	0.	1090.	56.1	167.	154.	67.	--	--	--	--	--	--
9/5/75	1.13	3.16	2370.		0.	1370.	72.7	172.	174.	88.	--	--	--	--	--	--
Station 105, T. 9 S., R. 14 E., Sec. 11 CBA																
7/25/74	0.28	2.89	844.	173.	0.	173.	31.0	--	21.2	10.2	--	--	--	--	--	--
8/13/74	0.56	3.02	889.	208.	0.	248.	45.8	--	25.0	20.0	--	--	--	--	--	--
9/16/74	0.08	3.86	498.	111.	0.	239.	42.8	--	11.4	15.7	--	--	--	--	--	--

(continued)

TABLE E-1 (continued)

Date	Flow (lps)	pH (lab)	Specific Conductance (µmhos)	Acidity (as CaCO3 mg/l)	Alkalinity (as CaCO3 mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 106, T. 9 S., R. 14 E., Sec 11 CBC																
8/26/74		2.61	2260.	478.	0.	714.	36.4	--	116.	17.9	--	--	--	--	--	--
Station 107, T. 9 S., R. 14 E., Sec. 10 DDD																
8/22/73		2.73	1250.	286.	0.	390.	55.8	--	29.1	22.7	0.06	3.87	0.135	0.01	--	--
7/25/74	6.23	2.93	819.	156.	0.	191.	31.1	--	13.7	8.9	--	--	--	--	--	--
8/13/74	1.98	2.90	1050.	223.	0.	322.	46.0	--	25.4	18.0	--	--	--	--	--	--
9/16/74	0.28	3.05	1060.	236.	0.	360.	42.4	--	16.0	21.3	--	--	--	--	--	--
10/15/74	0.25	3.07	970.	224.	0.	362.	39.0	--	11.0	24.1	--	--	--	--	--	--
Station 108, T. 9 S., R. 14 E., Sec. 11 CBA																
8/21/73	0.28	6.57	716.	--	16.	346.	104.	--	31.0	0.42	< 0.02	< 0.02	< 0.05	< 0.01	--	--
7/25/74	0.57	8.04	483.	--	42.	177.	10.9	--	9.7	0.1	--	--	--	--	--	--
8/13/74	0.14	7.10	687.	--	26.	320.	14.9	--	31.4	0.1	--	--	--	--	--	--
9/16/74	0.25	5.92	702.	--	5.	346.	14.6	--	35.3	0.17	--	--	--	--	--	--
10/15/74	0.57	4.88	718.	--	2.	359.	15.9	--	40.0	0.16	--	--	--	--	--	--
11/19/74	0.11	4.64	718.	--	0.	366.	15.7	--	42.2	--	--	--	--	--	--	--
7/18/75	2.27	6.48	451.	--	82.	144.	9.6	8.30	2.28	0.15	--	--	--	--	--	--
8/5/75	0.57	6.28	656.	--	88.	249.	11.1	14.2	1.96	0.25	--	--	--	--	--	--
9/5/75	0.28	5.83	733.	--	8.	370.	14.6	35.4	36.	0.55	--	--	--	--	--	--
Station 109, T. 9 S., R. 14 E., Sec. 10 DDC																
7/25/74	92.6	3.32	560.	98.3	0..	181.	14.5	--	7.0	8.3	--	--	--	--	--	--
8/13/74	29.7	3.02	963.	200.	0.	345.	25.8	--	25.5	20.	--	--	--	--	--	--
9/16/74	6.51	3.09	1240.	280.	0.	521.	30.8	--	32.2	28.	--	--	--	--	--	--
10.15/74	4.53	3.16	1320.	329.	0.	617.	32.9	--	28.0	39.	--	--	--	--	--	--
11/19/74	2.21	3.32	1270.	300.		634.	31.3	--	32.2	41.	--	--	--	--	--	--
1/23/74	2.27	3.26	1210.	305.	0.	639.	29.9	--	34.6	37.	--	--	--	--	--	--
2/19/74	2.27	3.25	1260.	275.	0.	573.	27.8	--	33.	33.8	--	--	--	--	--	--

(continued)

TABLE E-1 (continued)

Date	Flow (lps)	pH (lab)	Specific Conduc- tance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alka- linity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recov- erable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 109, T. 9 S., R. 14 E., Sec. 10 DDC																
5/15/75	5.95	3.64	437.	83.6	0.	203.	10.2	--	5.4	9.32	0.06	2.17	0.47	0.0037	--	--
6/7/75	56.9	--	--	--	-	--	--	99.	--	--	--	--	--	--	--	--
6/18/75	47.6	2.49	1070.	266.	0.	374.	16.	54.	31.6	22.4	< 0.005	7.9	0.68	--	--	--
7/1/75	173.	2.52	918.	228.	0.	317.	13.	44.3	23.6	16.4	< 0.05	6.5	0.73	--	--	--
7/18/75	166.	2.87	628.	142.	0.	218.	13.5	23.2	9.3	13.	0.070	4.8	0.510	0.020	--	--
8/5/75	33.4	2.70	782.	192.	0.	304.	19.5	29.4	10.8	18.	0.007	7.5	0.710	0.009	41.	12.
8/20/75	11.9	3.19	1030.	228.	0.	376.	24.0	37.8	23.3	23.5	--	--	--	--	49.	16.
9/5/75	9.06	3.42	1230.	289.	0.	510.	31.2	43.4	30.9	30.0	0.009	11.6	0.002	0.0015	62.	20.
9/23/75	5.10	3.44	1210.	304.	0.	569.	32.2	37.6	27.9	37.4	0.011	12.7	0.004	0.0049	69.	23.
Station 110, T. 9 S., R. 14 E., Sec. 11 CBA																
	Depth to Water(m)															
10/15/74	3.50	2.57	2720.	896.	0.	1130.	131.	--	209.	39.4	--	--	--	--	--	--
11/19/74	3.61	2.71	2770.	883.	0.	1080.	148.	--	238.	46.2	--	--	--	--	--	--
7/18/75	3.12	2.03	3080.	2110.	0.	2100.	66.3	610.	556.	109.	--	--	--	--	--	--
8/5/75	3.28	2.04	2840.	1940.	0.	2000.	76.8	520.	498.	92.5	--	--	--	--	--	--
9/5/75	3.56	2.94	2660.	1190.	0.	1330.	79.2	396.	336.	54.0	--	--	--	--	--	--
Station 127, T. 9 S., R. 14 E., Sec. 9 BAC																
	Flow (lps)															
8/5/75	226.	5.68	249.		4.	110.	10.1	5.00	--	0.15	< 6.005	1.83	0.250	0.001	31.	8.0
8/20/75	85.0	4.43	360.	62.8	0.	160.	12.5	7.5	--	3.76	0.003	3.18	0.36	0.0028	40.	1.6
9/5/75	56.6	4.41	431.	49.1	0.	206.	13.9	7.86	--	5.89	0.006	3.64	0.511	0.0032	50.	12.7
9/15/75	42.0	3.84	490.	59.1	0.	223.	14.4	9.28	--	6.8	0.005	4.02	0.559	0.0038	56.	16.6
Station 128, T. 9 S., R. 14 E., Sec. 4 CCA																
8/5/75	359.	6.13	154.		46.	28.	5.6	1.44	--	0.11	0.006	0.040	0.010	< 0.001	20.	4.8
8/20/75	283.	5.63	182.		47.	37.	5.6	1.67	--	0.07	0.0035	0.051	0.0283	< 0.001	25.	5.5
9/5/75	255.	6.23	210.		48.	51.	5.6	1.44	--	0.08	< 0.002	0.066	0.040	< 0.001	28.	6.8
9/15/75	227.	6.10	49.		49.	57.	5.5	1.86	--	0.09	< 0.002	0.395	0.0255	< 0.001	29.	7.2
Station 129, T. 9 S., R. 14 E., Sec. 9 BDD																
9/15/75	50.0	7.76	146.		87.	5.	3.5	0.16	--	0.05	0.002	0.001	0.001	0.001	21.	4.7

[a] Dashes indicate sample not tested.

TABLE E-2. WATER QUALITY ANALYSIS DATA--GLENGARY MINE AREA AND FISHER CREEK

Date	Flow (lps)	pH (lab)	Specific Conductance (µ mhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 201, T. 9 S., R. 14 E., Sec. 2 CCD																
8/22/73	--	2.57	1850.	254.	0.	602.	32.4	--	65.5	2.32	0.03	5.74	0.297	< 0.01	--	--
8/27/74	--	2.79	1790.	247.	0.	550.	30.0	--	90.0	2.50	--	--	--	--	--	--
9/16/74	--	2.67	2300.	416.	0.	768.	33.9	--	84.0	5.12	--	--	--	--	--	--
7/19/75	0.57	2.18	1780.	542.	0.	662.	16.7	132.	128.5	10.8	--	--	--	--	--	--
8/5/75	0.28	2.56	1850.	585.	0.	726.	23.0	130.	120.	9.7	--	--	--	--	--	--
Station 202, T. 9 S., R. 14 E., Sec. 2 CCD																
8/27/74	--	6.51	50.4	--	2.	16.2	3.6	--	0.07	0.11	--	--	--	--	--	--
9/16/74	--	6.02	65.2	--	2.	24.	5.1	--	0.48	0.45	--	--	--	--	--	--
6/22/75	1.13	3.87	182.	35.2	0.	66.	10.1	--	0.64	2.9	--	--	--	--	--	--
7/19/75	19.8	4.49	79.9	15.4	0.	26.2	3.6	0.79	1.14	1.15	--	--	--	--	--	--
8/5/75	9.06	7.63	78.7	--	5.	25.5	4.2	0.49	1.12	0.90	--	--	--	--	--	--
9/6/75	0.28	5.51	54.0	--	2.	19.2	4.2	0.43	0.09	0.58	--	--	--	--	--	--
Station 203, T. 9 S., R. 14 E., Sec. 11 BAB																
8/26/74	--	4.49	83.7	12.8	0.	31.	5.4	--	0.19	1.33	--	--	--	--	--	--
9/16/74	0.20	3.56	306.4	51.7	0.	80.	13.3	--	1.06	3.00	--	--	--	--	--	--
Station 204, T. 9 S., R. 14 E., Sec. 11 ABC																
7/26/74	--	3.91	117.	19.6	0.	24.0	6.6	--	0.80	1.3	--	--	--	--	--	--
8/27/74	--	4.26	90.7	15.8	0.	30.	7.7	--	1.15	1.39	--	--	--	--	--	--
9/16/74	0.57	3.99	154.	28.1	0.	46.	14.0	--	0.71	2.42	--	--	--	--	--	--
9/6/75	0.85	4.16	146.	--	0.	44.6	11.9	1.36	1.33	2.34	--	--	--	--	--	--
Station 205, T. 9 S., R. 14 E., Sec. 11 ABC																
8/21/73		2.74	1140.	174.	0.	332.	34.9	--	51.	4.21	0.05	1.38	0.245	< 0.01	--	--
7/26/74		2.84	999.	150.	0.	231.	23.3	--	39.4	5.0	--	--	--	--	--	--
6/27/74		2.92	1250.	181.	0.	345.	31.4	--	49.8	6.7	--	--	--	--	--	--
9/16/74	3.40	2.98	1140.	153.	0.	326.	29.6	--	45.3	5.13	--	--	--	--	--	--
10/14/74	2.28	3.28	1060.	149.	0.	341.	30.1	--	32.4	5.2	--	--	--	--	--	--
11/20/74	2.21	3.25	1030.	126.	0.	288.	27.6	--	33.9	6.0	--	--	--	--	--	--
2/4/75	2.28	3.31	879.	130.	0.	305.	30.0	--	29.8	4.3	--	--	--	--	--	--
5/18/75	1.13	2.91	1080.	156.	0.	330.	29.7	--	35.2	4.6	0.07	0.65	0.33	< 0.002	--	--
6/18/75	1.93	2.37	1340.	271.	0.	355.	25.0	75.	75.	6.9	--	3.65	0.32	--	--	--

(continued)

TABLE E-2 (continued)

Date	Flow (lps)	pH (lab)	Specific Conductance (μmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 205, T. 9 S., R. 14 E., Sec. 11 ABC (Continued)																
7/1/75	7.08	2.42	1100.	209.	0.	258.	13.2	56.5	52.5	3.0	<0.05	2.88	0.21	--	--	--
7/19/75	14.7	2.89	491.	53.6	0.	106.	9.5	25.4	14.4	1.35	0.014	1.03	0.170	0.020	--	--
8/5/75	6.80	2.46	1040.	202.	0.	351.	24.2	47.	38.5	6.34	0.014	2.88	0.330	0.013	--	--
8/20/75	2.55	3.23	1120.	188.	0.	338.	30.2	51.6	47.5	6.5	--	--	--	--	--	--
9/6/75	2.55	3.32	1180.	158.	0.	331.	31.5	46.6	42.6	6.0	0.017	1.36	<0.002	0.001	--	--
9/23/74	1.98	3.39	1020.	147.	0.	318.	31.2	42.2	40.8	5.5	0.025	0.94	0.0025	0.001	--	--
Station 206, T. 9 S., R. 14 E., Sec. 11 ABC																
8/23/74	--	2.88	871.	128.	0.	240.	29.6	--	25.8	3.72	--	--	--	--	--	--
7/26/74	--	4.35	74.1	16.0	0.	18.6	14.1	--	0.10	1.6	--	--	--	--	--	--
8/27/74	--	4.30	55.3	13.4	0.	24.0	16.2	--	0.04	1.14	--	--	--	--	--	--
9/16/74	0.20	4.45	62.0	12.6	0.	22.0	16.6	--	0.07	1.22	--	--	--	--	--	--
10/14/74	0.57	4.62	63.0	15.6	0.	28.0	17.2	--	0.19	1.4	--	--	--	--	--	--
9/6/75	0.57	4.43	66.3	27.7	0.	25.4	16.4	0.29	0.41	1.30	--	--	--	--	--	--
Station 207, T. 9 S., R. 14 E., Sec. 11 ACA																
7/29/74	96.2	3.62	244.	32.6	0.	51.0	14.4	--	2.98	1.8	--	--	--	--	--	--
8/27/74	--	3.56	374.	46.2	0.	98.0	19.9	--	6.4	2.56	--	--	--	--	--	--
9/16/74	12.1	3.31	366.	47.4	0.	114.	23.2	--	4.0	2.59	--	--	--	--	--	--
10/14/74	8.50	3.72	386.	50.0	0.	124.	24.2	--	4.41	2.86	--	--	--	--	--	--
11/20/74	4.42	3.83	400.	44.8	0.	118.	25.7	--	5.22	3.56	--	--	--	--	--	--
12/18/74	4.53	3.77	350.	39.8	0.	124.	26.5	--	4.97	2.8	--	--	--	--	--	--
1/22/75	3.12	3.83	391.	47.2	0.	132.	27.4	--	4.45	3.3	--	--	--	--	--	--
2/4/75	3.12	3.99	383.	50.9	0.	134.	27.	--	3.85	3.2	--	--	--	--	--	--
2/18/75	3.12	3.70	390.	43.8	0.	122.	27.	--	3.75	3.2	--	--	--	--	--	--
3/20/75	3.12	3.67	341.	46.2	0.	121.	27.8	--	1.68	3.2	--	--	--	--	--	--
4/14/75	3.12	3.58	224.	42.5	0.	113.	25.7	--	1.55	2.9	--	--	--	--	--	--
5/14/75	12.2	3.66	285.	37.	0.	92.	20.7	--	2.63	2.48	0.04	0.71	0.15	<0.002	--	--
5/18/75		3.38	387.	57.6	0.	111.	18.0	--	5.9	3.65	0.07	0.83	0.18	<0.002	--	--
6/7/75	24.6	--	--	--	--	--	--	4.05	--	--	--	--	--	--	--	--
6/18/75	71.7	3.60	147.	10.2	0.	44.	11.3	1.9	1.5	1.5	<0.005	0.47	0.05	--	--	--
7/1/75	283.	3.59	139.	27.5	0.	35.	9.6	3.6	2.33	1.34	<0.05	0.53	0.58	--	--	--
7/19/75	164.	3.73	116.	21.9	0.	32.4	8.4	3.33	1.40	1.0	0.060	0.440	0.050	0.010	--	--
8/5/75	16.4	3.38	225.	34.	0.	57.1	13.5	3.49	1.74	1.94	0.006	0.700	0.075	<0.002	8.7	2.4
8/20/75	15.9	3.89	289.	20.1	0.	77.5	17.8	4.50	3.75	2.37	--	--	--	--	11.6	3.3

(continued)

TABLE E-2 (continued)

Date	Flow (lps)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Conper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 207, T. 9 S., R. 14 E., Sec. 11 ACA (Continued)																
9/6/75	9.35	3.62	340.	51.4	0.	102.	22.5	4.10	3.98	2.69	0.0098	0.817	0.132	0.0012	16.5	4.7
9/23/75	25.2	3.85	350.	46.7	0.	107.	23.4	3.80	4.28	2.64	0.0073	0.796	0.141	0.001	18.0	5.4
Station 208, T. 9 S., R. 14 E., Sec. 12 CBC																
9/16/73		3.82	196.	81.	0.	58.	19.5	--	1.74	1.19	< 0.02	0.48	0.08	< 0.01	--	--
12/5/73		3.82	209.	22.	0.	80.0	20.1	1.24	2.93	1.62	--	0.44	--	--	--	--
7/26/74		4.31	89.4	9.7	0.	25.	8.9	--	0.86	0.80	--	--	--	--	--	--
8/27/74		4.06	172.	24.5	0.	49.	14.5	--	1.70	1.34	--	--	--	--	--	--
9/16/74		3.77	215.	25.3	0.	68.	18.3	--	1.17	1.60	--	--	--	--	--	--
10/14/74		4.30	235.	25.4	0.	82.	18.8	--	1.39	1.94	--	--	--	--	--	--
11/20/74		4.22	253.	31.9	0.	80.	19.3	--	1.24	2.3	--	--	--	--	--	--
12/18/74		4.32	233.	25.6	0.	86.	19.6	--	1.08	2.0	--	--	--	--	--	--
1/22/75		4.19	233.	26.	0.	78.	20.8	--	0.82	2.3	--	--	--	--	--	--
2/4/75		4.35	230.	27.4	0.	79.	21.1	--	0.73	2.1	--	--	--	--	--	--
2/18/75		4.06	288.	25.3	0.	80.	20.8	--	0.78	2.1	--	--	--	--	--	--
3/20/75		3.97	215.	24.	0.	76.	21.2	--	0.51	2.	--	--	--	--	--	--
4/14/75		3.94	208.	22.7	0.	72.	19.8	--	0.35	1.7	--	--	--	--	--	--
5/14/75		4.19	139.	17.6	0.	49.0	13.4	--	0.28	1.08	0.06	0.32	0.07	< 0.002	--	--
6/18/75		4.47	73.6	11.6	0.	24.	7.5	0.70	0.49	0.6	--	--	--	--	--	--
7/1/75		4.56	105.	7.9	0.	19.4	5.6	2.87	0.27	0.25	--	--	--	--	--	--
7/19/75		4.48	65.9	9.9	0.	19.6	6.2	1.09	0.61	0.45	--	--	--	--	--	--
8/5/75	227.	3.97	109.	17.4	0.	37.4	9.4	1.11	0.69	0.97	--	--	--	--	--	--
9/6/75	28.3	4.40	173.	15.2	0.	55.2	15.6	0.73	0.72	1.59	--	--	--	--	--	--
Station 209, T. 9 S., R. 14 E., Sec. 18 CAA																
9/16/73		6.49	108.		10.	38.	9.9	--	0.20	< 0.5	0.02	0.05	0.02	< 0.01	11.6	3.2
8/6/75	34.0	6.02	98.6		12.	28.	7.1	0.23	0.02	0.11	0.008	0.050	0.020	< 0.001	10.7	2.0
8/21/75	25.4	5.72	101.		14.	31.	9.1	0.11	0.03	0.06	< 0.002	0.067	0.017	< 0.001	11.7	3.1
9/5/75	56.6	5.91	106.		7.	37.	9.4	0.14	0.03	< 0.05	0.006	0.0605	0.023	< 0.001	11.7	2.8
9/16/75	84.9	5.56	105.		6.	38.	9.0	0.64	0.03	0.10	0.0029	0.0618	0.027	< 0.001	11.3	3.0

(continued)

TABLE E-2 (continued)

Date	Flow (lps)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)[a]	Alkalinity (as $CaCO_3$ mg/l)[a]	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
	Depth to Water (m)															
Station 210, T. 9 S., R. 14 E., Sec. 11 BBA																
9/16/74	1.36	4.16	192.	29.7	0.	76.	10.3	--	6.10	1.59	--	--	--	--	--	--
10/14/74	1.76	4.56	127.	23.7	0.	48.	11.7	--	12.8	1.27	--	--	--	--	--	--
6/22/75	1.22	4.01	137.	22.6	0.	44.	8.9	--	1.0	1.82	--	--	--	--	--	--
7/1/75	1.22	3.99	151.	31.3	0.	46.	9.0	6.4	1.13	1.67	--	--	--	--	--	--
8/5/75	1.45	3.65	175.	52.2	0.	47.7	11.1	75.2	0.97	2.15	--	--	--	--	--	--
9/6/75	1.41	4.02	122.	11.0	0.	44.5	9.4	27.9	7.6	3.7	--	--	--	--	--	--
	Depth to Water (m)															
Station 211, T. 9 S., R. 14 E., Sec. 2 CCD																
6/22/75	0.55	2.33	1730.	767.	0.	927.	80.7	--	23.7	62.4	--	--	--	--	--	--
7/1/75	0.30	2.24	2310.	1330.	0.	1550.	80.7	100.	91.	120.	--	--	--	--	--	--
7/19/75	0.46	2.13	2060.	821.	0.	914.	61.0	97.	114.	64.4	--	--	--	--	--	--
8/5/75	1.03	2.41	2050.	852.	0.	968.	52.	139.	130.	49.	--	--	--	--	--	--
Station 213, T. 9 S., R. 14 E., Sec. 20 ACC																
8/6/75	343.	7.00	64.8		19.	10.9	5.2	0.10	0.00	0.09	< 0.005	0.020	0.010	< 0.001	8.0	1.4
8/21/75	259.	5.54	75.4		16.	14.8	5.6	0.06	0.01	0.06	< 0.002	0.0105	0.001	< 0.001	8.7	1.8
9/5/75	226.	6.34	80.7		16.	19.4	6.1	0.10	0.03	< 0.05	0.006	0.0132	0.009	< 0.001	9.5	2.1
9/16/75	339.	5.82	83.5		15.	27.	6.3	0.09	0.01	< 0.05	0.0029	0.0104	0.0125	< 0.001	10.2	2.1
Station 214, R. 9 S., R. 15 E., Sec. 17 CDB																
9/16/75	71.	6.93	85.5		12.0	23.6	6.6	0.13	0.04	< 0.05	0.003	0.01	0.012	< 0.001	10.6	2.14

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[a] Dashes indicate sample not tested.

TABLE E-3. WATER QUALITY ANALYSIS DATA--McLAREN MILL AREA AND SODA BUTTE CREEK

Date	Flow (lps)	pH (lab)	Specific Conductance (μmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 317, T. 9 S., R. 14 E., Sec. 25 ADB																
8/20/73	72.8	8.18	238.	--[a]	118.	8.3	9.2	--	--	< 0.5	< 0.02	< 0.02	< 0.02	< 0.01	--	--
6/10/74	628.	7.91	170.	--	77.	12.0	8.1	--	--	--	< 0.01	< 0.01	0.02	< 0.01	--	--
7/8/74	606.	7.89	188.	--	84.	8.8	9.0	--	--	--	< 0.02	< 0.01	0.01	< 0.01	--	--
7/24/74	245.	7.97	228.	--	112.	7.6	9.8	--	--	< 0.1	--	--	--	--	--	--
8/12/74	133.	8.43	234.	--	127.	7.4	11.4	--	0.01	< 0.1	< 0.01	< 0.01	< 0.01	< 0.01	--	--
9/17/74	60.8	8.13	234.	--	111.	9.4	9.7	--	0.02	< 0.1	0.03	< 0.01	< 0.01	< 0.01	--	--
10/14/74	53.0	7.88	203.	--	94.	9.6	9.0	--	0.02	< 0.1	< 0.02	< 0.01	< 0.01	< 0.01	--	--
11/18/74	30.0	8.47	250.	--	129.	9.2	7.6	--	3.26	< 0.1	--	--	--	--	--	--
12/16/74	17.0	8.23	259.	--	118.	10.4	8.0	--	0.03	< 0.1	--	--	--	--	--	--
1/13/75	12.5	7.98	239.	--	114.	8.6	9.8	--	1.50	0.1	--	--	--	--	--	--
2/5/75	9.63	7.74	248.	--	118.	8.9	9.5	--	0.03	< 0.1	--	--	--	--	--	--
2/18/75	9.35	7.95	246.	--	117.	10.2	9.6	--	< 0.01	< 0.1	--	--	--	--	--	--
3/19/75	13.0	8.09	246.	--	116.	10.2	7.9	--	0.03	< 0.1	--	--	--	--	--	--
4/14/75	7.93	8.21	247.	--	118.	10.4	8.2	--	< 0.01	< 0.1	--	--	--	--	--	--
5/19/75	94.3	7.94	239.	--	112.	14.5	7.0	--	0.05	0.10	0.05	0.01	0.01	0.0020	40.00	6.80
6/5/75	852.	--	--	--	--	--	--	0.13	--	--	--	--	--	--	--	--
6/17/75	920.	6.93	157.	--	64.	10.3	7.1	0.18	0.25	0.08	--	0.10	0.01	--	25.00	4.50
7/2/75	1620.	6.78	122.	--	30.	62.	6.4	2.8	0.18	< 0.05	< 0.05	0.08	0.01	--	19.80	4.00
7/20/75	--	7.76	206.	--	99.	9.9	7.9	0.05	0.15	< 0.05	< 0.002	0.040	0.010	0.010	34.80	5.70
7/30/75	991.	6.58	249.	--	82.	38.9	7.3	16.9	0.08	< 0.05	0.060	0.050	0.020	0.020	--	--
8/4/75	250.	7.52	230.	--	114.	9.5	7.7	0.19	0.07	0.07	0.060	0.006	0.003	< 0.002	--	--
8/19/75	146.	7.67	228.	--	114.	10.5	7.7	0.40	0.03	0.05	--	--	--	--	39.40	7.00
9/4/75	79.0	8.20	232.	--	117.	8.2	8.1	0.06	0.28	0.05	0.005	0.0048	0.0136	< 0.001	40.00	7.40
9/23/75	71.1	7.54	231.	--	118.	7.2	7.9	0.09	0.12	0.06	< 0.003	0.011	0.012	< 0.001	38.80	6.80
Station 319, T. 9 S., R. 14 E., Sec. 25 ACD																
6/10/74	173.	7.67	129.	--	43.	19.4	8.2	--	--	--	< 0.02	0.01	0.02	< 0.01	--	--
7/8/74	396	7.65	92.6	--	35.	9.8	6.3	--	--	--	--	--	--	--	--	--
8/12/74	36.0	6.84	140.	--	51.	14.8	7.7	--	< 0.01	< 0.01	--	--	--	--	--	--
Station 320, T. 9 S., R. 14 E., Sec. 25 ACD																
8/20/73	--	3.71	1400.	174.	0.	775.	13.2	--	172.	< 0.5	< 0.02	0.06	0.21	< .01	--	--
9/22/73	--	2.20	4590.	3600.	0.	402.	36.8	--	1300.	116.	0.18	44.8	1.70	0.02	--	--
12/5/73	--	4.68	1480	14.2	0.	741.	10.7	124.	179.	0.26	--	.04	--	--	--	--
5/2/74	--	7.60	348.	--	109.	59.0	7.6	--	--	--	< 0.02	0.02	0.08	< 0.01	--	--
6/10/74	--	4.48	1370.	167.	0.	854.	12.2	--	198.	--	< 0.02	< 0.01	0.26	0.01	--	--

(continued)

TABLE E-3 (continued)

Date	Flow (lps)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 320, T. 9 S., R. 14 E., Sec. 25 ACD (ontinued)																
6/20/74	7.65	3.27	1520.	83.6	0.	788.	16.5	--	46.4	1.8	0.02	0.04	0.27	< 0.01	--	--
7/8/74	34.0	3.90	1490.	64.5	0.	856.	14.9	--	41.6	0.5	0.05	0.06	0.31	< 0.01	--	--
8/12/74	5.95	4.20	1740.	168.	0.	1070.	17.6	--	86.2	< 0.1	0.07	0.01	0.40	0.01	--	--
9/17/74	--	3.69	1450.	39.2	0.	837.	29.6	.	48.	< 0.1	0.04	< 0.01	0.30	< 0.01	--	--
7/2/75	11.0	5.78	994.	--	11.	497.	10.7	48.5	13.	0.15	--	--	--	--	--	--
7/20/75	--	6.07	1120.	--	4.	608.	11.3	57.2	21.1	0.10	--	--	--	--	--	--
8/4/75	6.51	4.86	1150.	56.6	--	671.	10.7	62.	21.6	0.10	0.060	0.008	0.137	0.014	--	--
9/4/75		4.48	1180.	57.6	0.0	716.	11.8	70.6	35.8	0.89	0.0065	0.0075	< 0.002	< 0.001	--	--
Station 321, T. 9 S., R. 14 E., Sec. 25 ACD																
7/8/74	7.08	5.64	1210.	--	27.	705.	9.0	--	119.	< 0.1	--	--	--	--	--	--
8/12/74	3.68	6.23	1080.	--	4.	593.	8.1	--	100.	< 0.1	--	--	--	--	--	--
9/17/74	2.27	3.80	1340.	116.	0.	762.	9.8	--	152.	< 0.1	--	--	--	--	--	--
10/14/74	1.78	3.87	1360.	148.	0.	802.	9.8	--	148.	< 0.1	--	--	--	--	--	--
11/18/74	1.44	3.85	1370.	157.	0.	788.	9.6	--	149.	< 0.1	--	--	--	--	--	--
12/16/74	1.78	4.12	1310.	195.	0.	772.	9.3	--	176.	< 0.1	--	--	--	--	--	--
1/13/75	1.78	4.41	1260.	176.	0.	730.	9.8	--	128.	< 0.1	--	--	--	--	--	--
2/6/75	1.78	4.02	1180.	154.	0.	694.	9.8	--	167.	0.1	--	--	--	--	--	--
3/19/75	1.61	3.71	1160.	141.	0.	656.	8.6	--	126.	< 0.1	--	--	--	--	--	--
4/14/75	1.44	3.76	1080.	98.3	0.	584.	7.7	--	128.	0.1	--	--	--	--	--	--
5/19/75	3.79	4.93	915.	116.	0.	490.	8.6	--	136.	0.12	0.08	0.02	0.09	< 0.002	--	--
6/5/75	6.70	--	--	--	-	--	--	335.	--	--	--	--	--	--	--	--
6/17/75	8.21	4.08	1540.	309.	0.	929.	10.5	282.	460.	0.05	--	0.17	0.23	--	--	--
7/2/75	7.08	4.52	1270.	211.	0.	737.	9.6	186.	149.	0.09	--	--	--	--	--	--
7/20/75	11.6	4.99	1080.	144.	0.	590.	8.8	143.	122.	0.08	0.050	0.050	0.110	0.020	--	--
8/4/75	3.12	5.50	1080.	--	16.	556.	8.3	141.	106.	.10	0.050	0.011	0.098	0.006	--	--
9/4/75	9.35	4.14	993.	118.	0.	542.	8.8	122.	127.	.84	0.005	0.047	0.002	0.001	--	--
Station 322, T. 9 S., R. 14 E., Sec. 25 ACD																
8/20/73	60.9	7.48	340.	--	109.	66.0	9.2	.	7.4	< 0.5	< 0.02	< 0.02	< 0.02	< 0.01	--	--
6/10/74	917.	7.81	192.	--	69.	30.0	--	--	--	--	--	0.01	--	--	--	--
7/8/74	1090.	7.67	157.	--	54.	22.0	7.1	--	--	--	--	--	--	--	--	--
7/24/74	439.	8.44	230.	--	98.	28.	8.2	--	--	< 0.1	--	--	--	--	--	--
8/12/74	170.	7.61	293.	--	104.	43.	11.3	--	< 0.01	< 0.1	--	--	--	--	--	--
9/17/74	33.	8.17	362.	--	87.	92.	7.7	--	1.14	< 0.1	--	--	--	--	--	--

(continued)

TABLE E-3 (continued)

Date	Flow (lps)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 322, T. 9 S., R. 14 E., Sec. 25 ACD (Continued)																
10/14/74	15.9	7.77	392.	--	99.	115.	6.1	--	0.71	< 0.1	--	--	--	--	--	--
11/18/74	10.8	8.26	481.	--	86.	167.	5.5	--	2.10	< 0.1	--	--	--	--	--	--
12/16/74	7.08	6.82	696.	--	62.	306.	5.6	--	35.8	< 0.1	--	--	--	--	--	--
1/13/75	5.38	6.42	640.	--	66.	265.	6.9	--	6.0	< 0.1	--	--	--	--	--	--
2/5/75	5.38	6.21	800.	--	50.	378.	7.8	--	49.4	< 0.1	--	--	--	--	--	--
2/18/75	3.96	6.32	826.	--	42.	401.	7.	--	46.2	< 0.1	--	--	--	--	--	--
3/19/75	3.96	6.50	798.	--	51.	372.	7.3	--	9.0	< 0.1	--	--	--	--	--	--
4/14/75	7.08	6.26	779.	--	64.	323.	6.8	--	34.5	< 0.1	--	--	--	--	--	--
5/19/75	74.5	7.24	279.	--	60.	71.	6.0	--	0.17	0.11	0.05	0.03	0.02	0.002	42.00	8.80
6/5/75	855.	--	--	--	--	--	--	5.65	--	--	--	--	--	--	--	--
6/17/75	1120.	6.57	148.	--	59.	15.5	7.0	0.47	0.22	0.06	< 0.005	0.10	0.01	--	23.00	4.00
7/2/75	2700.	6.74	104.	--	46.	11.9	5.6	16.2	11.5	4.56	0.07	0.5	0.08	--	19.80	6.00
7/20/75	--	7.18	154.	--	62.	17.7	6.3	1.25	0.10	0.05	0.050	0.030	0.010	0.010	25.60	4.00
7/30/75	990.	6.81	255.	--	68.	50.5	6.5	18.2	0.07	0.05	0.050	0.030	0.010	0.020	--	--
8/4/75	272.	6.77	277.	--	96.	40.7	7.3	5.2	0.06	0.11	< 0.002	0.004	0.007	< 0.002	42.80	7.90
8/19/75	110.	7.14	308.	--	104.	57.7	7.5	8.7	1.46	.05	--	--	--	--	47.00	10.30
9/4/75	94.6	6.97	350.	--	105.	72.6	7.9	9.1	0.36	0.05	< 0.005	0.0037	0.0085	< 0.001	54.00	12.40
9/23/75	48.7	7.29	367.	--	105.	81.7	7.5	11.5	0.84	0.05	< 0.005	0.0025	0.0073	< 0.001	53.80	13.50
Station 325, T. 9 S., R. 14 E., Sec. 33 ACD																
5/19/75	1250.	7.47	143.	--	59.	12.9	7.9	1.17	--	0.10	0.0064	0.0018	0.002	< 0.001	19.10	5.30
6/17/75	8300.	7.91	121.	--	50.	11.4	8.6	1.44	--	0.11	< 0.005	0.0030	< 0.005	< 0.002	16.00	4.00
7/2/75	--	6.73	91.3	--	37.	6.4	7.3	55.6	--	0.12	< 0.005	0.0023	0.002	< 0.001	10.40	2.10
7/15/75	--	6.41	79.4	--	33.	6.1	7.1	6.58	--	0.10	< 0.005	0.0020	0.002	0.005	9.70	2.10
8/4/75	--	6.46	129.	--	54.	8.0	9.4	0.89	--	0.07	< 0.005	0.002	< 0.001	< 0.001	17.10	3.50
8/19/75	--	5.96	169.	--	74.	12.7	8.9	0.54	--	< 0.05	0.0073	< 0.001	< 0.001	< 0.001	23.00	5.10
9/4/75	--	6.79	197.	--	80.	22.	9.1	0.81	--	0.05	0.008	0.0024	0.005	< 0.001	26.00	6.50
9/23/75	991.	6.79	206.	--	90.	11.1	8.8	0.54	--	< 0.05	0.004	0.0039	0.0115	< 0.001	28.00	6.50
Station 326, T. 58 N., R. 109 W., Sec. 21 BCC (Wyoming)																
5/19/75	2550.	7.72	174.	--	74.	11.6	10.9	0.94	--	0.13	< 0.005	0.0015	0.0065	< 0.001	23.00	6.30
6/17/75	9540.	7.92	136.	--	59.	9.5	9.4	1.55	--	0.08	< 0.005	0.002	< 0.005	< 0.002	17.60	5.00
7/2/75	--	6.67	95.2	--	40.	5.9	8.3	19.1	--	0.12	< 0.005	0.002	< 0.002	< 0.001	11.40	2.40
7/15/75	--	6.55	94.5	--	41.	5.9	8.8	4.11	--	0.08	< 0.005	< 0.001	< 0.002	< 0.001	11.90	2.70
8/4/75	--	6.52	150.	--	68.	10.6	10.1	0.70	--	0.10	< 0.005	0.001	< 0.001	< 0.001	20.00	4.70

(continued)

TABLE E-3 (continued)

Date	Flow (lps)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 326, T. 58 N., R. 109 W., Sec. 21 BCC (Wyoming) (Continued)																
8/19/75	--	5.98	193.	--	89.	12.4	10.3	0.40	--	0.06	< 0.002	< 0.001	< 0.001	< 0.001	26.00	6.40
9/4/75	--	6.92	226.	--	100.	16.3	10.7	0.23	--	0.05	0.002	0.0024	0.0039	< 0.001	30.00	8.00
9/14/75	1330.	6.65	240.	--	103.	23.	10.3	0.19	--	0.06	0.005	0.0064	< 0.001	< 0.001	32.00	8.80
Station 327, T. 57 N., R. 109 W., Sec. 6 DBC																
5/19/75	2550.	7.87	204.	--	89.	12.7	10.8	0.53	--	0.10	< 0.005	0.0010	< 0.001	< 0.0010	26.00	7.80
6/17/75	9770.	7.95	145.	--	64.	10.0	10.0	1.64	--	0.10	< 0.005	0.0030	< 0.005	< 0.0020	19.20	5.00
7/2/75	--	7.39	104.	--	45.	6.8	9.2	19.8	--	0.10	< 0.005	0.0030	< 0.002	< 0.0010	12.80	3.10
7/15/75	--	7.62	109.	--	47.	6.0	9.6	3.68	--	0.08	< 0.005	0.0010	< 0.003	< 0.0010	13.60	3.60
8/4/75	--	6.49	160.	--	76.	10.9	10.9	0.52	--	0.05	< 0.005	0.002	< 0.001	< 0.001	23.00	4.60
8/19/75	--	6.28	202.	--	99.	11.3	11.6	0.38	--	0.07	0.0071	< 0.001	< 0.001	< 0.001	28.00	7.20
9/4/75	--	8.05	222.	--	107.	13.5	11.8	0.23	--	0.05	< 0.002	0.0025	0.004	< 0.001	31.00	9.20
9/14/75	1980.	7.32	246.	--	111.	16.9	11.8	0.15	--	0.05	0.0070	0.0045	0.0187	< 0.001	33.00	9.40

[a] Dashes indicate sample not tested.

TABLE E-4. WATER QUALITY ANALYSIS DATA--McLAREN MILL TAILINGS

Date	Depth to Water (m)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 301, T. 9 S., R. 14 E., Sec. 25 ADB																
5/2/74	2.65	7.48	350.	--[a]	51.	108.	2.6	--	--	--	--	--	--	--	--	--
6/10/74	0.16	7.37	130.	--	44.	20.0	4.2	--	--	--	< 0.02	< 0.01	0.01	< 0.01	--	--
7/10/74	1.17	7.26	1060.	--	280.	377.	11.1	--	--	--	--	--	--	--	--	--
7/2/75	0.73	6.99	820.	--	183.	278.	8.3	2.07	0.10	< 0.05	--	--	--	--	--	--
Station 302, T. 9 S., R. 14 E., Sec. 25 ADC																
6/10/74	0.04	7.77	111.	--	56.	1.6	4.3	--	--	< 0.1	< 0.02	< 0.01	0.01	< 0.01	--	--
7/10/74	2.12	7.64	435.	--	224.	6.8	11.1	--	--		< 0.02	< 0.01	0.02	< 0.01	--	--
8/12/74	2.18	8.42	361.	--	184.	15.8	15.3	--	0.23	0.1	--	--	--	--	--	--
9/17/74	2.30	7.91	307.	--	117.	32.	2.6	--	1.40	0.62	< 0.02	0.05	0.01	< 0.01	--	--
10/14/74	2.30	8.03	319.	--	124.	46.	5.3	--	0.27	0.14	0.15	< 0.01	< 0.01	< 0.01	--	--
11/18/74	2.35	7.71	404.	--	190.	23.	11.4	--	--	0.1	--	--	--	--	--	--
6/5/75	1.16	--	--	--	--	--	--	4.50	--	--	--	--	--	--	--	--
6/17/75	1.58	7.31	227.	--	112.	9.5	4.6	2.7	0.58	0.43	--	--	--	--	--	--
7/2/75	2.04	7.02	366.	--	208.	8.6	7.3	7.5	0.78	0.25	< 0.05	0.10	0.02	--	--	--
7/20/75	2.17	6.65	384.	--	200.	9.1	10.5	19.2	0.29	0.20	--	--	--	--	--	--
8/4/75	2.09	6.97	387.	--	204.	6.9	10.9	1.25	0.42	0.05	--	--	--	--	--	--
9/4/75	2.38	7.24	414.	--	212.	15.2	10.3	14.6	0.49	0.37	< 0.005	0.0085	0.012	< 0.001	--	--
Station 303, T. 9 S., R. 14 E., Sec. 25 ADC																
5/14/74	2.81	6.24	2240.	--	87.	1580.	17.0	--	21.3	--	0.09	4.91	0.74	--	--	--
6/10/74	0.54	6.11	870.	--	31.	481.	7.7	--	--	--	0.02	0.30	0.11	< 0.01	--	--
7/10/74	1.20	5.68	1730.	--	24.	1080.	12.2	--	--	--	--	--	--	--	--	--
8/12/74	3.24	5.39	3180.	--	19.	2420.	21.3	--	316.	0.4	--	--	--	--	--	--
6/17/75	0.30	6.74	123.	--	55.	6.1	2.4	--	0.09	0.08	--	--	--	--	--	--
7/2/75	0.76	6.07	763.	--	42.	183.	4.7	2.71	0.17	< 0.05	--	--	--	--	--	--
7/20/75	0.66	4.48	1570.	123.	0.	989.	--	31.4	24.	0.30	--	--	--	--	--	--
8/4/75	1.33	3.46	2120.	188.	0.	1320.	17.3	41.4	28.6	1.15	--	--	--	--	--	--
9/4/75	3.01	5.47	3360	--	28.	2400.	17.6	335.	312.	0.52	--	--	--	--	--	--
Station 304, T. 9 S., R. 14 E., Sec. 25 ACD																
5/15/74	4.57	3.52	2460.	207.	0.	1780.	32.5	--	104.	--	0.10	1.08	0.37	--	--	--
6/10/74	2.20	2.91	2310.	823.	0.	1410.	25.0	--	438.	9.3	0.02	2.11	0.80	0.01	--	--
7/10/74	2.29	2.81	1730.	444.	0.	757.	17.5	--	201.	3.7	--	--	--	--	--	--

(continued)

TABLE E-4 (continued)

Date	Depth to Water (m)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 304, T. 9 S., R. 14 E., Sec. 25 ACD (continued)																
8/12/74	4.48	2.92	6900.	3840.	0.	6140.	34.2	--	2060.	1.0	--	--	--	--	--	--
6/17/75	1.80	2.20	2570.	845.	0.	1460.	18.8	--	480.	16.3	--	--	--	--	--	--
7/2/75	1.86	2.71	1770.	563.	0.	1010.	21.4	300.	275.	3.08	--	--	--	--	--	--
7/20/75	1.66	2.22	1770.	491.	0.	769.	17.5	224.	215.	3.80	--	--	--	--	--	--
8/4/75	2.34	2.35	1450.	405.	0.	625.	17.3	178.	168.	2.47	--	--	--	--	--	--
9/4/75	3.81	3.31	6210	3640.	0.	5680.	22.5	1740.	1810.	3.9	--	--	--	--	--	--
Station 305. T. 9 S., R. 14 E., Sec. 25 ADC																
6/10/74	1.32	6.70	1900.	--	166.	1140.	17.1	--	--	--	0.02	0.03	0.03	< 0.01	--	--
7/10/74	1.68	6.45	2870.	--	356.	1660.	23.5	--	--	--	--	--	--	--	--	--
8/12/74	2.06	6.62	3210.	--	444.	1850.	32.6	--	35.	< 0.1	--	--	--	--	--	--
9/17/74	2.71	7.68	2880.	--	238.	1760.	17.1	--	100.	0.10	--	--	--	--	--	--
10/14/74	3.06	6.60	3140.	--	469.	1450.	15.4	--	120.	0.10	--	--	--	--	--	--
11/18/74	3.33	6.62	4050.	--	421.	1770.	19.1	--	145.	0.48	--	--	--	--	--	--
12/16/74	3.65	6.50	4010.	--	370.	1770.	17.5	--	140.	< 0.1	--	--	--	--	--	--
1/13/75	3.91	6.36	3010.	--	281.	1860.	15.0	--	134.	< 0.1	--	--	--	--	--	--
2/5/75	3.89	6.13	3200.	--	112.	1970.	15.8	--	299.	< 0.1	--	--	--	--	--	--
2/18/75	4.15	5.79	3080.	--	116.	2000.	15.3	--	290.	< 0.1	--	--	--	--	--	--
3/19/75	4.68	5.85	3000.	--	56.	2030.	18.7	--	150.	0.2	--	--	--	--	--	--
4/14/75	5.29	5.98	3100.	--	158.	1990.	19.3	--	72.	0.1	--	--	--	--	--	--
5/19/75	1.52	7.03	2150.	--	141.	1280.	8.3	--	0.44	0.12	0.11	0.06	0.06	< 0.002	--	--
6/5/75	1.13	--	--	--	--	--	--	1.11	--	--	--	--	--	--	--	--
6/17/75	1.31	6.68	2510.	--	243.	1440.	13.0	0.97	0.34	0.07	--	--	--	--	--	--
7/2/75	1.77	6.87	2440.	--	301.	1450.	16.7	2.6	1.37	< 0.05	0.10	0.15	0.07	--	--	--
7/20/75	1.61	7.02	2500.	--	324.	1460.	18.1	1.89	1.62	0.05	--	--	--	--	--	--
8/4/75	1.64	6.88	2630.	--	322.	1710.	20.9	1.30	2.07	< 0.05	--	--	--	--	--	--
9/4/75	2.25	6.95	2760.	--	420.	1570.	25.5	5.7	11.8	0.26	--	--	--	--	--	--
Station 306, T. 9 S., R. 14 E., Sec. 25 ACD																
6/10/74	0.56	7.01	579.	--	182.	152.	9.4	--	--	--	< 0.02	0.01	0.02	< 0.02	--	--
7/10/74	0.46	7.15	750.	--	226.	200.	11.6	--	--	--	--	--	--	--	--	--
8/12/74	1.00	7.76	843.	--	250.	22.1	14.1	--	0.22	< 0.1	--	--	--	--	--	--
9/17/74	2.98	7.53	984.	--	236.	324.	20.1	--	0.40	0.10	--	--	--	--	--	--
10/14/74	3.84	6.87	1840.	--	188.	810.	14.3	--	93.6	0.12	--	--	--	--	--	--
11/18/74	4.13	7.69	1100.	--	188.	505.	10.7	--	64.	< 0.1	--	--	--	--	--	--

(continued)

TABLE E-4 (continued)

Date	Depth to Water (m)	pH (lab)	Specific Conduc- tance (μmhos)	Acidity (as $CaCO_3$ mg/l)	Alka- linity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recov- erable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 306, T. 9 S., R. 14 E., Sec. 25 ACD (continued)																
12/16/74	4.22	6.88	1470.	--	396.	529.	17.1	--	70.5	< 0.1	--	--	--	--	--	--
1/13/75	4.48	6.56	1570.	--	365.	612.	16.4	--	68.5	< 0.1	--	--	--	--	--	--
2/18/75	5.27	7.03	1300.	--	476.	292.	19.6	--	58.	1.2	--	--	--	--	--	--
6/17/75	0.43	6.76	103.	--	36.	8.8	2.2	--	0.21	0.11	--	--	--	--	--	--
7/2/75	0.55	6.69	90.9	--	37.	5.8	2.4	5.	0.27	0.06	--	--	--	--	--	--
Station 307, T. 9 S., R. 14 E., Sec. 25 ACD																
5/2/74	5.15	6.46	4990.	--	227.	3590.	12.6	--	--	--	--	--	--	--	--	--
6/10/74	2.11	3.01	3710.	916.	0.	2790.	38.9	--	429.	7.7	0.10	15.93	2.69	0.05	--	--
7/10/74	2.00	3.04	4020.	1180.	0.	2890.	44.5	--	536.	17.3	--	--	--	--	--	--
8/12/74	3.78	6.28	3550.	--	301.	2300.	21.9	--	56.	0.1	--	--	--	--	--	--
6/17/75	1.83	2.35	3260.	483.	0.	2050.	24.0	--	238.	8.	--	--	--	--	--	--
7/2/75	1.74	2.80	3650.	1250.	0.	2550.	43.	590.	568.	28.4	--	--	--	--	--	--
Station 308, T. 9 S., R. 14 E., Sec. 25 ACD																
6/10/74	2.59	3.29	4780.	273.	0.	4610.	12.8	--	418.	0.5	0.16	0.68	0.38	0.01	--	--
7/10/74	1.96	5.95	7090.	--	568.	6410.	24.4	--	538.	0.01	--	--	--	--	--	--
8/12/74	3.26	4.06	16200.	13200.	0.	19600.	27.0	--	7900.	2.0	0.40	0.20	11.4	0.05	--	--
5/19/75	2.65	6.65	2170.	--	69.	1210.	8.7	--	2.34	0.32	0.11	0.99	0.34	< 0.002	--	--
6/17/75	2.62	2.67	3840.	2640.	0.	2600.	12.2	--	166.	0.10	--	--	--	--	--	--
7/2/75	2.38	4.54	6540.	1850.	0.	6570.	16.5	1070.	1030.	0.24	--	--	--	--	--	--
7/20/75	1.71	4.42	7970.	2180.	0.	7510.	15.6	1350.	1270.	0.14	0.260	0.110	1.11	0.040	--	--
8/4/75	1.90	4.62	4370.	2210.	0.	3180.	18.0	410.	365.	0.17	--	--	--	--	--	--
9/4/75	2.93	4.49	3760.	280.	0.	3200.	15.4	245.	355.	2.40	< 0.005	0.0476	< 0.002	< 0.001	--	--
Station 310, T. 9 S., R. 14 E., Sec. 25 ADC																
12/5/73	4.97	3.41	22600.	22600.	0.	33400.	28.9	--	13100.	207.	--	8.7	--	--	--	--
6/10/74	2.21	3.66	7750.	3990.	0.	7490.	33.3	--	2450.	0.9	0.16	0.73	0.87	0.01	--	--
7/8/74	2.60	5.64	8140.	--	216.	9240.	35.3	--	2430.	--	0.19	0.30	0.79	0.01	--	--
8/12/74	3.57	4.34	10600.	7460.	0.	11400.	40.9	--	4390.	2.5	0.27	0.14	1.25	0.01	--	--
9/17/74	3.67	2.94	12200.	7520.	0.	12400.	45.7	--	4780.	3.19	0.30	0.44	1.50	0.10	--	--
10/14/74	3.73	3.94	11400.	9500.	0.	14200.	37.2	--	5160.	5.15	0.34	0.89	1.60	0.02	--	--
11/18/74	3.76	4.43	13600.	10700.	0.	16500.	19.6	--	6320.	5.55	0.35	0.93	2.50	0.02	--	--
6/5/75	2.62	--	--	--	--	--	--	1900.	--	--	--	--	--	--	--	--

(continued)

TABLE E-4 (continued)

Date	Depth to Water (m)	pH (lab)	Specific Conductance (µmhos)	Acidity (as $CaCO_3$ mg/l)	Alkalinity (as $CaCO_3$ mg/l)	Sulfate (mg/l)	Silica (mg/l)	Iron Total Recoverable (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Lead (mg/l)	Copper (mg/l)	Zinc (mg/l)	Cadmium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)
Station 310, T. 9 S., R. 14 E., Sec. 25 ADC (continued)																
6/17/75	2.26	2.58	7640.	3340.	0.	6820.	34.2	1920.	1840.	1.37	--	0.86	0.64	--	--	--
7/2/75	2.32	3.41	6750.	3260.	0.	6970.	28.2	1800.	1730.	3.25	0.18	7.4	0.8	--	--	--
7/20/75	2.17	2.80	7870.	3280.	0.	7290.	28.7	2020.	1820.	5.55	0.230	6.70	0.890	0.030	--	--
8/4/75	2.68	3.07	8790.	4880.	0.	9050.	30.1	2720.	2560.	24.4	--	--	--	--	--	--
9/4/75	3.86	4.08	10400.	--	0.	11200.	23.7	3660.	3680.	21.4	< 0.005	6.09	< 0.002	< 0.001	--	--
Station 311, T. 9 S., R. 14 E., Sec. 25 ADC																
5/14/74	3.88	2.51	9400.	6910.	0.	9690.	52.5	--	3690.	--	0.26	120.	6.0	--	--	--
6/10/74	1.17	3.02	2040.	538.	0.	1230.	14.5	--	283.	1.0	< 0.02	0.26	0.43	< 0.01	--	--
7/10/74	1.75	3.00	1930.	396.	0.	1020.	14.2	--	184.	0.6	--	--	--	--	--	--
8/12/74	3.61	3.53	7850.	683.	0.	7630.	72.3	--	2590.	38.4	--	--	--	--	--	--
9/17/74	4.61	4.14	14300.	13200.	0.	17600.	62.0	--	7540.	11.0	--	--	--	--	--	--
6/17/75	1.28	2.49	2330.	574.	0.	1310.	12.7	--	324.	0.87	--	--	--	--	--	--
7/2/75	1.31	3.12	2020.	556.	0.	1260.	13.5	290.	282.	0.67	--	--	--	--	--	--
Station 312, T. 9 S., R. 14 E., Sec. 25 ACD																
6/17/75	2.44	6.99	373.	--	162.	22.	7.1	--	0.77	0.74	--	--	--	--	--	--
7/2/75	3.35	6.95	404.	--	208.	13.5	8.6	23.2	1.8	0.25	--	--	--	--	--	--
7/20/75	3.31	7.01	551.	--	312	19.7	9.2	27.7	11.7	--	--	--	--	--	--	--
Station 313, T. 9 S., R. 14 E., Sec. 25 ACD																
6/17/75	1.83	6.98	831.	--	469.	30.	14.2	--	0.39	0.33	--	--	--	--	--	--
7/2/75	0.64	7.03	694.	--	364.	17.9	9.4	0.57	0.30	0.10	--	--	--	--	--	--
Station 314, T. 9 S., R. 14 E., Sec. 25 ACD																
8/12/74	3.82	5.70	26300.	--	181.	49900.	27.6	--	20600.	1.5	--	--	--	--	--	--
7/2/75	3.69	5.90	8770.	--	314.	7240.	11.6	1290.	1380.	0.7	--	--	--	--	--	--
Station 315, T. 9 S., R. 14 E., Sec. 25 ACD																
6/17/75	1.82	4.41	3800.	951.	0.	3120.	30.8	--	635.	1.68	--	--	--	--	--	--
7/2/75	1.95	4.42	4320.	895.	0.	3360.	29.2	1620.	1510.	1.65	--	--	--	--	--	--
Station 316, T. 9 S., R. 14 E., Sec. 25 ADB																
6/17/75	1.10	6.28	1200.	--	56.	617.	15.	--	0.84	0.21	--	--	--	--	--	--
7/2/75	1.40	6.11	746.	--	48.	346.	15.2	7.0	5.4	0.27	--	--	--	--	--	--
7/20/75	1.34	6.58	459.	--	64.	161.	10.4	8.3	0.36	0.14	--	--	--	--	--	--
8/4/75	2.22	6.25	655.	--	56.	268.	15.7	6.5	3.2	0.26	--	--	--	--	--	--

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[a] Dashes indicate sample not tested.

APPENDIX F

TABLE F-1. CHEMISTRY OF SNOW SAMPLES

Constituent	Ca	Mg	Na	K	Fe	Mn	SiO_2	HCO_3	Cl	SO_4	F	Pb[a]	Zn	Cu	Cd
Location															
Cemetery near mill site	0.29	0.08	0.2	0.2	0.04	.01	1.0	1.46	1.30	13.7	.05	3.9	8.5	1.0	1.0
By cabin, McLaren mine site	0.24	0.06	0.2	0.1	0.01	.01	1.0	1.46	2.65	10.4	.05	2.0	10.0	5.2	1.0
Site 211	0.38	0.09	0.3	0.2	0.05	.01	1.0	0.98	2.00	9.7	.05	2.0	4.0	1.0	1.0
McLaren pit	--[b]	--	--	--	--	--	--	--	--	--	--	4.0	51.2	10.3	1.5
Glengary at back of cirque	--	--	--	--	--	--	--	--	--	--	--	4.1	11.0	3.5	1.3
Site 204	--	--	--	--	--	--	--	--	--	--	--	2.6	1.0	1.4	1.0
Site 207	--	--	--	--	--	--	--	--	--	--	--	2.0	10.9	2.3	1.0

[a] Micrograms per liter, all other milligrams per liter.
[b] Dash indicates sample not tested.

APPENDIX G

SUMMARY OF WELL AND DRILLING DATA

Eleven wells were constructed during the summer of 1973 within the tailings pond materials, using a large backhoe and 4-inch heavy plastic casing. During the 1974 field season, five more wells were added at the mill site, and nine wells were installed in the mine areas. Wells in this second group were shallower due to the use of a smaller backhoe (see Table G-1). A Mobile-50 drilling truck was employed during the 1975 field season; 28 wells were drilled, primarily to gain information and samples pertaining to the mineralogy, stratigraphy, and hydrology or the depth of oxidation in the mill and mine sites. The drilling records are summarized in Table G-1; the comments were taken from the field notes of the geologist in charge, Larry Higgins in 1973, Joe Wallace in 1974, and John Sonderegger in 1975.

TABLE G-1. DRILLING SUMMARY

Site and hole no.	Altitude of land surface (m)	Depth (m)	Casing (m)	Comments[a] (measurements in m)
McLaren mill site				
1	2330.26	3.14	Yes, 3.05	Tailings and gravel 1.3-1.9; tailings 1.9-3.1; TD in gravel and boulders.
2	2334.55	2.62	Yes, 2.44	Sand and gravel 0-2.6; TD in gravel and boulders.
3	2329.84	4.57	Yes, 4.57	Sand and gravel with streaks of tailings 0.91-1.83; fine sand with some gravel 1.83-4.57.
4	2329.50	6.10	Yes, 6.10	Tailings 0.61-5.49; 5.49-6.10 brown gravel and cobbles (small amount of water seeping in from sides).
5	2329.57	6.52	Yes, 6.40	Tailings 1.22-6.52; saturated clay and tailings in bottom 1.22-1.83; TD in boulders and gravel; hole sides slumping.
6	2327.80	5.55	Yes, 5.49	Sand and clay with some boulders 0-3.96; gravel and boulders with stumps and tree trunks (old creek bed) 3.96-5.55; TD in creek bed; water.
7	2328.04	5.70	Yes, 5.49	Tailings with some clay 0.46-4.60; clay and sand with some boulders and tailings 4.60-5.70.
8	2328.69	7.32	Yes, 7.32	Tailings 6.10-7.01; boulders and gravel 7.01-7.32.

(continued)

TABLE G-1. (continued)

Site and hole no.	Altitude of land surface (m)	Depth (m)	Casing (m)	Comments[a] (measurements in m)
McLaren mill site (continued)				
9	?	3.66	No	Tailings 0.61-2.44; boulders and gravel 2.44-3.66.
10	2331.49	5.64	Yes, 5.49	Tailings 0.46-5.18; boulders and gravel 5.18-5.64.
11	2330.55	5.94	Yes, 5.79	Tailings 0.61-5.94; TD in boulders.
12	2333.38	3.66	Yes, 3.66	Sand and gravel 0-3.66.
13	2330.98	3.75	Yes, 3.66	Sand and gravel 0-3.75.
14	2329.15[b]	4.27	Yes, 4.27	Tailings 0.67-4.27.
15	2330.44	3.96	Yes, 3.96	Tailings, 0.91-3.96.
16	2331.03	3.05	Yes, 3.05	Gravel and cobbles 0-3.05.
17	2329.99	5.79	Yes, 6.10	Tailings 0.91-5.18; gravel 5.18-5.79.
18	2329.99	5.94	Yes, 6.10	Tailings 0.61-5.49; gravel and tailings 5.49-5.94.
19	2329.60	5.64	Yes, 6.10	Tailings (gray-green pyritic) 0.76-3.05 (black; damp) 3.05-3.96, (black and brown) 3.96-5.64; gravel at bottom.
20	2329.90	6.86	Yes, 6.92	Tailings (green) 0.85-2.13, (black-brown, dry) 2.13-3.66, (gray-green, silty, wet) 3.66-6.71; gravel 6.71-6.86.

(continued)

TABLE G-1. (continued)

Site and hole no.	Altitude of land surface (m)	Depth (m)	Casing (m)	Comments[a] (measurements in m)
McLaren mill site (continued)				
21	2329.87	5.94	Yes, 6.10	Tailings (blue-green) 0.76-1.52, (gray-green) 1.52-5.64; gravel 5.64-5.94; water table at 3.05-3.35; could hear water entering hole from unknown depth.
22[c]	2330.38	6.86	Yes, 6.74	Tailings 1.22-6.25; sand and "hematite" 6.25-6.34; gravel 6.34-6.86; water table at about 3.35.
23[c]	2329.93	6.40	Yes, 6.77	Tailings (normal) 0.61-1.83, (with oxidized material) 1.83-2.13, (normal) 2.13-3.26, (oxidized) 3.26-3.35, (normal) 3.35-3.90, (clay and pyrite) 3.90-4.27, (normal) 4.27-4.57; gravel 4.57-5.94; gravel with sand lenses 5.94-6.40.
24A[d]	2327.50	17.65	Yes, 6.10	Tailings 0.46-8.84; gravel 8.84-13.72; granite 13.72-17.65; "soft zone" 15.54-15.85; pyrite noted, minor chlorite.
24B[d]	2328.25	22.95	Yes, 6.10	Tailings ?-3.81; gravel 3.81-18.29; diorite 18.29-22.95.
25	2329.21	9.14	Yes, 8.53	Tailings 0.61-6.71; gravel 6.71-9.14.
26	2329.28	8.38	Yes, 8.23	Tailings 0.91-7.16; gravel 7.16-8.38.

(continued)

TABLE G-1. (continued)

Site and hole no.	Altitude of land surface (m)	Depth (m)	Casing (m)	Comments[a] (measurements in m)
McLaren mill site (continued)				
27	2329.45	8.38	Yes, 6.10	Tailings 0.91-6.86; gravel and tailings 6.86-7.92; gravel 7.92-8.38.
28[c]	2329.57	6.10	Yes, 6.10	Tailings (with sand and gravel) 0.76-1.07, (normal) 1.07-3.32, (oxidized-contamination?) 3.32-3.35, (normal) 3.35-5.33; gravel 5.33-6.10.
29[c]	2329.38	7.01	Yes, 6.10	Tailings (mixed with gravel) 1.52-2.13, (high clay) 2.13-2.44, (silty) 2.44-2.74, (normal, wet) 2.74-3.35, (normal) 3.35-6.86; gravel 6.86-7.01.
30[c]	2330.51	5.18	Yes, 5.18	Tailings 0.76-4.82, minor oxidized zone (contamination?) at 3.05; gravel 4.82-5.18.
31[c]	2331.42	3.66	No	Sand and tailings 1.52-2.74; no recovery 2.74-3.05; sand and gravel 3.05-3.66.
32	2330.32	2.74	No	Gravel and sand 0-2.74.
33[c]	2328.56	7.47	Yes, 6.10	Tailings (normal) 0.61-1.52, (no recovery) 1.52-2.13, (sandy and silty) 2.13-3.35, (silty) 3.35-3.96, (with pebbles) 3.96-4.57, (normal) 4.57-6.40, (clay rich) 6.40-7.01,(normal) 7.01-7.38; gravel 7.38-7.47.

(continued)

TABLE G-1. (continued)

Site and hole no.	Altitude of land surface (m)	Depth (m)	Casing (m)	Comments[a] (measurements in m)
McLaren mill site (continued)				
34[c]	2327.76	8.23	Yes, 6.10	Tailings 0.76-8.14, oxidized zones at 1.13, 2.74-3.35 interval, creek overflow? or "dirt" in 2.13-2.74 interval; gravel 8.14-8.23.
35[d]	--[e]	6.71	Yes, 4.88	Tailings 2.29-2.90, and 3.05-4.27; gravel 2.90-3.05 and 4.27-4.57; gravel with sand lenses 4.57-5.12; boulders 5.12-6.71.
36[d]	--	11.49	Yes, 7.13	Gravel 0-3.05 and 4.11-6.10; sand (trace pyrite) 3.05-4.11; sand and gravel 6.10-6.77; granite 6.77-11.19.
McLaren mine site				
110	2944.51	3.51	Yes, 3.66	Oxidized sulfide ores, 0-3.51.
111	2934.61	2.99	Yes, 3.05	Oxidized wastes (some sulfides) 0-2.99.
112	2954.07	2.04	Yes, 2.13	Oxidized and weathered soil 0-1.83.
113	2944.04	3.69	Yes, 3.96[f]	Oxidized wastes (some sulfides) 0-3.69.
114	2925.28	3.02	Yes, 3.35[f]	Oxidized wastes 0-3.02.
115	2937.33	3.96	Yes, 4.27[f]	Soil and waste 0-3.96.
Au 1	--[e]	5.18	Yes	Oxidized rock and soil 0-5.18; dry.

(continued)

TABLE G-1. (continued)

Site and hole no.	Altitude of land surface (m)	Depth (m)	Casing (m)	Comments[a] (measurements in m)
McLaren mine site (continued)				
Au 2	--[e]	6.86	Yes	Silt, sand, and sulfides (outer surface oxidized but centers fresh) 0-4.88; "gravelly", poor recovery 4.88-5.49; finer material--silt, sand, and small pebbles; 6.10-6.86--not sure--may be weathered bedrock.
Au 3	--	6.86	Yes	Gravel and wastes (strongly oxidized) 0-0.91; gravel and wastes 0.91-2.13; mine wastes, clay, silt- and sand-size, wet at 3.05, oxidized 2.13-5.03; coarse wastes 5.03-6.10; soft wastes (predominantly clay) 6.10-6.71; gravel 6.71-6.86.
Au 4	--	3.05	Yes	Oxidized clay with ore pebbles 0-2.13; cobbles of bedrock? 2.13-3.05.
Au 5	--	8.38	Yes	Clay- and silt-size wastes 0-1.83, coarse mine waste 1.83-2.44; clay- and silt-size waste 2.44-3.66; coarse (gravel to cobble size) waste 3.66-3.96; fairly soft clay, silt- and sand-size material 3.96-7.92; sand-size pyrite and rock pebbles 7.92-8.38; oxidized to bottom 0.46. TD very hard drilling (cobbles to boulders?).

(continued)

TABLE G-1. (continued)

Site and hole no.	Altitude of land surface (m)	Depth (m)	Casing (m)	Comments[a] (measurements in m)
McLaren mine site (continued)				
Au 6	--[e]	5.49	Yes	Sand, minor clay and some ore pebbles 0-3.05; increasingly coarser material becoming damp 3.05-4.57; gravel- and sand-size waste 4.57-5.49; TD on hard material (boulder?).
Glengary mine site				
210	2963.50	1.83	Yes, 1.83	Soil 0-1.83.
211	2970.45	2.50	Yes, 2.74	Soil 0-1.83; weathered bedrock 1.83-2.50.
212	2970.55	1.37	Yes, 1.37[f]	Soil 0-1.07; weathered bedrock 1.07-1.37.
Au 1	--[e]	13.72	Yes, 12.19	Blue-gray sulfides and clay; harder at 13.41-13.72.

[a] At mill site, the first 0.46-1.52 m is material added in recontouring unless otherwise noted.

[b] Altitude of casing top (land surface is about 1 m lower).

[c] Split spoon core holes.

[d] Diamond drill core holes.

[e] Altitude not determined.

[f] 50.8 mm (outside diam.) pipe for water-level measurements only.

APPENDIX H

TABLE H-1. WATER LEVELS - McLAREN MILL SITE[a]

Station	1973 Oct. 8	1973 November 8	30	1974 Feb. 25	March 22	May 14	21	29	June 6	10	17	25	July 1	8	16	1974 24
301	--[b]	--	--	--	--	11.13	12.47	13.98	13.99	13.93	13.56	13.55	13.25	12.91	12.46	11.90
302	15.85	15.79	15.79	sc[c]	sc	sc	sc	16.86	18.18	18.20	16.27	16.15	16.11	16.12	16.07	16.01
303	--	--	--	--	--	10.79	11.98	--	13.27	13.06	13.11	13.02	12.79	12.40	11.63	11.75
304	--	--	--	--	--	8.64	8.69	10.67	11.28	11.01	11.38	11.62	11.34	10.92	10.49	9.98
305	9.18	9.79	8.99	9.03	sc	9.44	9.90	11.55	12.02	11.81	11.49	11.47	11.51	11.45	11.38	11.31
306	7.38	6.29	6.69	6.38	5.99	9.57	9.45	10.64	10.98	10.91	11.13	11.18	11.12	11.01	10.93	10.81
307	--	--	--	--	--	7.62	7.65	9.05	9.64	9.46	9.88	10.06	9.89	9.57	9.25	11.88
308	--	--	--	--	--	--	--	9.02	9.73	9.71	9.98	10.26	10.46	10.34	10.10	9.76
310	10.13	10.24	10.27	10.21	10.57	11.54	11.73	12.47	12.93	12.87	12.97	13.00	12.90	12.47	12.22	11.93
311	--	--	--	--	--	10.22	10.66	12.28	12.99	12.94	13.06	13.08	12.81	12.35	11.94	11.84
312	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
313	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
314	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
315	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
316	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

(continued)

TABLE H-1 (continued)

Station	1974 July 29	August 5	12	20	26	September 6	13	24	October 1	7	14	22	November 6	11	18	1974 26
301	11.60	10.98	--	--	--	--	--	--	--	--	--	--	--	--	--	--
302	15.98	16.12	16.06	15.74	15.96	15.93	15.97	15.90	15.92	15.96	15.94	15.93	15.90	15.90	15.89	15.88
303	11.34	10.93	10.36	9.91	9.49	9.28	--	--	--	--	--	--	--	--	--	--
304	9.75	9.29	8.73	8.26	8.38	7.67	7.36	--	--	--	--	--	--	--	--	--
305	11.25	10.38	11.06	10.93	11.09	10.64	10.48	10.30	10.23	10.13	10.07	9.98	10.17	9.80	9.80	9.67
306	10.71	10.66	10.47	9.90	9.67	9.09	8.70	8.10	7.81	7.63	7.63	7.47	7.41	7.39	7.34	7.30
307	8.63	8.26	7.80	7.37	7.44	6.69	6.20	--	--	--	--	--	--	--	--	--
308	9.60	9.33	9.01	8.65	8.65	8.21	8.04	7.43	7.25	7.12	7.04	6.86	6.97	6.89	6.75	6.55
310	11.79	11.59	11.51	11.54	11.54	11.48	11.45	11.41	11.25	11.38	11.34	11.32	11.27	11.26	11.32	11.21
311	11.32	10.82	10.50	10.27	10.18	10.01	9.75	9.17	8.95	8.76	--	--	--	--	--	--
312	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
313	--	--	--	--	--	11.10	--	--	--	--	--	--	--	--	--	--
314	--	--	8.21	8.11	7.88	--	--	--	--	--	--	--	--	--	--	--
315	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
316	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

(continued)

TABLE H-1 (continued)

Station	1974 December 3	11	16	1975 January 3	8	13	22	29	February 5	12	18	24	March 5	13	19	1975 25
301	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
302	15.83	15.85	15.82	15.81	15.79	--	--	--	15.86	15.81	sc	sc	sc	sc	sc	sc
303	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
304	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
305	9.63	9.60	9.48	9.39	9.32	9.22	9.16	9.15	9.24	9.03	8.98	8.90	8.80	8.57	8.45	8.25
306	7.28	7.31	7.25	7.25	7.09	6.99	6.95	7.20	6.73	6.21	6.20	5.96	--	--	--	--
307	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
308	6.37	6.79	6.83	6.53	6.40	6.27	6.39	6.99	6.37	6.29	6.31	6.31	6.18	5.93	5.88	5.86
310	11.20	11.17	11.15	11.08	11.17	11.05	11.01	10.95	10.36	10.47	10.65	10.51	10.41	10.40	--	--
311	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
312	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
313	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
314	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
315	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
316	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

(continued)

TABLE H-1 (continued)

Station	1975 April 1	9	14	23	30	May 8	17	19	27	June 5	12	17	22	July 1	9	1975 20
301	--	--	--	--	--	--	12.36	14.22	12.53	13.93	14.09	14.09	13.41	13.37	13.80	13.41
302	sc	sc	sc	sc	sc	sc	sc	sc	sc	17.13	17.12	16.64	16.57	16.18	16.33	16.21
303	--	--	--	--	--	--	13.73	--	9.52	13.73	13.09	13.31	13.01	12.84	13.23	12.94
304	--	--	--	--	--	--	--	--	7.67	10.34	11.16	11.41	11.07	11.32	11.84	11.55
305	8.12	7.88	7.84	7.76	7.75	7.57	11.44	11.60	8.84	11.99	11.97	11.83	12.12	11.36	11.57	11.52
306	--	--	--	--	--	--	11.61	--	8.03	11.61	10.83	11.05	10.96	10.92	11.24	11.17
307	--	--	--	--	--	--	--	--	6.51	8.39	9.49	9.75	9.56	9.83	10.22	10.07
308	5.76	5.32	5.26	--	--	--	9.02	9.64	8.53	9.95	9.52	9.67	9.67	9.94	10.36	10.59
310	--	--	--	--	--	--	--	--	10.58	12.30	12.51	12.83	12.73	12.74	13.11	12.91
311	--	--	--	--	--	--	--	--	9.56	11.26	12.42	12.81	12.64	12.78	13.20	12.94
312	--	--	--	--	--	--	--	--	--	13.60	14.55	14.67	14.44	13.76	14.06	13.80
313	--	--	--	--	--	--	--	--	--	--	12.64	13.36	13.58	14.55	14.36	13.94
314	--	--	--	--	--	--	--	--	--	8.20	dry	7.76	8.00	8.34	8.68	9.26
315	--	--	--	--	--	--	--	--	--	10.91	11.53	11.73	11.37	12.91	12.17	11.80
316	--	--	--	--	--	--	--	--	--	12.04	13.36	13.34	13.03	13.23	13.80	13.30

(continued)

TABLE H-1 (continued)

	1975							1975
	July	August				September		
Station	29	4	13	19	26	4	9	22
301	13.04	12.73	12.22	11.80	11.31	--	--	--
302	16.10	16.15	15.98	16.07	16.11	16.00	15.98	16.05
303	12.55	12.27	11.81	11.54	11.21	10.73	10.32	9.29
304	11.22	10.87	10.50	10.15	9.81	9.40	8.78	7.72
305	11.49	11.47	11.34	11.32	11.21	11.05	10.96	10.65
306	11.08	10.98	10.81	10.79	10.67	10.28	9.90	9.21
307	9.82	9.57	9.26	9.00	8.73	8.39	7.84	6.71
308	10.57	10.40	10.20	10.04	9.85	9.65	9.52	9.02
310	12.64	12.40	12.14	11.98	11.72	11.37	11.36	11.31
311	12.61	12.25	11.82	11.63	11.41	11.09	10.86	10.12
312	--	--	--	--	--	--	--	--
313	13.63	13.48	13.25	13.18	13.03	12.75	12.57	12.03
314	9.65	9.26	9.11	9.03	8.85	8.54	8.37	7.78
315	11.46	11.09	10.70	10.33				
316	12.84	12.43	11.98					

[a] Elevation is 2316.48 m. All measurements are in m.
[b] Dash indicates no measurable water level in well.
[c] Snow cover, well not located and measured.